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SOLAR EFFECTS ON BUILDING DESIGN.

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A REPORT OF A PROGRAM HELD AS PART OF THE BUILDING RESEARCH INSTITUTE 1962 SPRING CONFERENCE ON THE SOLAR EFFECTS ON BUILDING DESIGN. TOPICS DISCUSSED ARE--(1) SOLAR ENERGY DATA APPLICABLE TO BUILDING DESIGN, (2) THERMAL EFFECTS OF SOLAR RADIATION ON MAN, (3) SOLAR EFFECTS ON ARCHITECTURE, (4) SOLAR EFFECTS ON BUILDING COSTS, (5) SELECTION OF GLASS AND SOLAR SHADING TO REDUCE COOLING DEMAND, (6) DESIGN OF WINDOWS, (7) DESIGN OF SKYLIGHTS, (8) DESIGN OF ELECTRIC ILLUMINATION, (9) WINDOW DESIGN IN EUROPE--A REVIEW OF RECENT LITERATURE, AND (10) SWEDISH PRACTICES IN WINDOW DESIGN. ALSO INCLUDED ARE OPEN FORUM DISCUSSIONS AND CONFERENCE SUMMARY. THE CONFERENCE ATTEMPTED TO DEFINE VARIOUS PROBLEMS AND REVIEW SOME OF THE MEANS AT HAND TO SLOVE THEM. TWO OF THE EFFECTS OF SOLAR ENERGY ON BUILDING DESIGN WERE DISCUSSED--LIGHT AND HEAT. THE UNDESIRABLE SOLAR EFFECTS OF AIR-CONDITIONED COMMERCIAL BUILDINGS WAS MAINLY DEALT WITH. SEVERAL SPECIFIC NEEDS HAVE BEEN PROMINENTLY INDICATED BY THIS CONFERENCE--(1) THE NEED FOR BETTER COMMUNICATION REGARDING THIS SUBJECT AND THE NEED FOR MORE GENERALLY AVAILABLE INFORMATION, PRESENTED IN TERMS READILY UNDERSTOOD BY THE AVERAGE ARCHITECT, WHOSE RESPONSIBILITY IT IS TO TRANSLATE THESE PRINCIPLES INTO BUILDING DESIGN, (2) THE NEED FOR MUCH MORE OBJECTIVE AND UNPREJUDICED RESEARCH IN THIS FIELD, AND (3) THE NEED FOR MORE BRI CONFERENCES ON THIS SUBJECT. CHARTS AND DIAGRAMS ACCOMPANY THE TEXT COPIES OF THIS PUBLICATION MAY ALSO BE OBTAINED FROM THE BUILDING RESEARCH INSTITUTE, 1725 DESALES STREET, N.W., WASHINGTON, D.C. 20036. PRICE $10.00. (RK)

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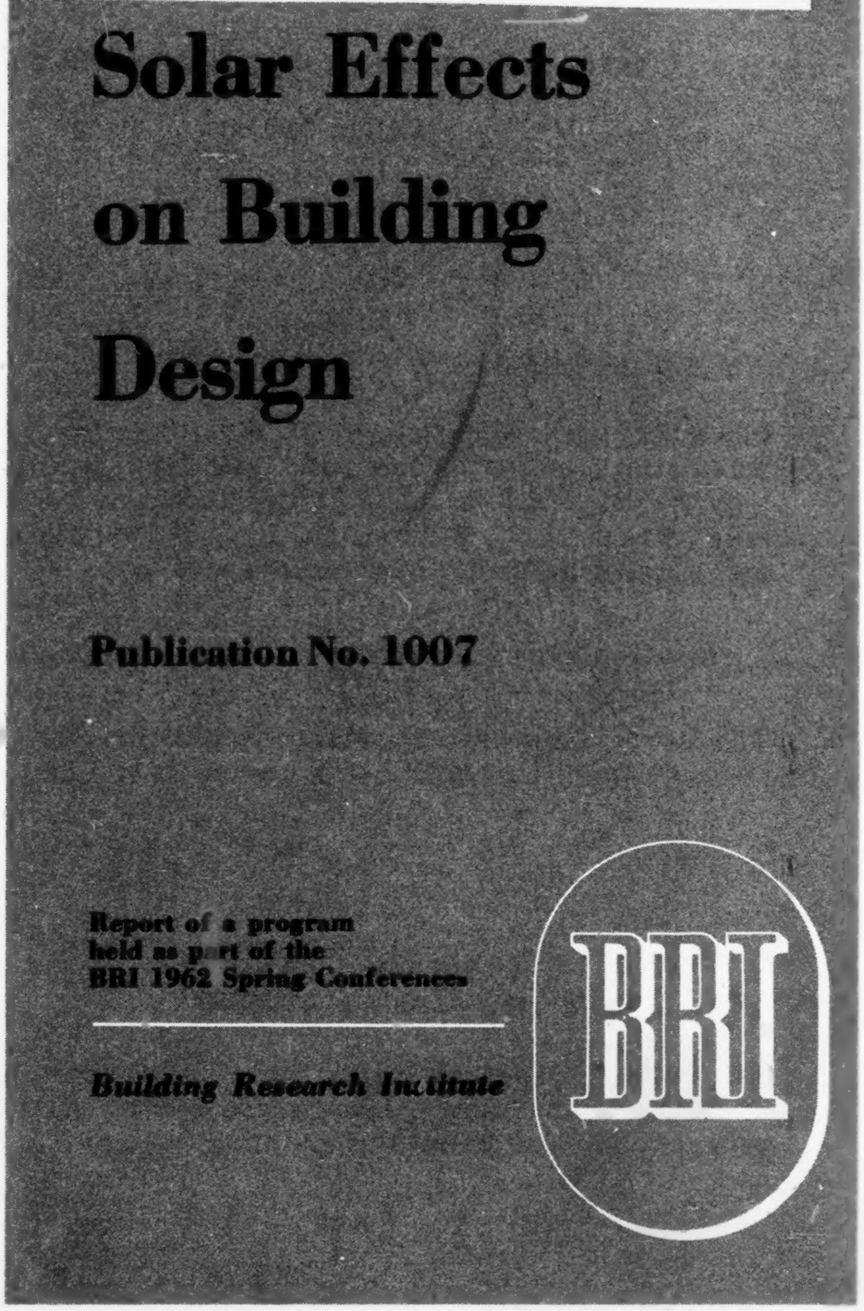

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Building Research Institute

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Inquiries concerning Solar Effects on Building Design or other publications resulting from the BRI 1962 Spring Conferences may be directed to the Building Research Institute, 1725 De Sales Street, N.W., Washington, D. C. 20036. The other publication resulting from these conferences is:

New Joint Sealants: Criteria, Design, and Materials

The list of conference registrants appears in New Joint Sealants, and a complete list of BRI publications is included in each book.

ACKNOWLEDGMENT

The Building Research Institute gratefully acknowledges the contributions to building science made by the participants in the program on Solar Effects on Building Design.

Milton C. Coon Jr.

MILTON C. COON, JR.
Executive Vice President

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Keynote Address

Effects of Solar Radiation on Man

by Henry L. Logan, Holophane Company, Inc.

Abstract: Because of his critical interior temperature, man's life expectancy is largely dependent on his control over his external natural environment, i.e., control over the direct and indirect effects of solar radiation. It is the function of building to provide the optimum range in man's environment, taking into account the effects of the seasons, temperature, humidity, light, uniformity of climate, static atmospheric charge, and air movement on man's energy, health, safety, and longevity. We need to learn more about designing buildings to enclose a specific optimum climate, insulating their occupants from unfavorable variations of solar radiation and developing the optimum thermostable state for unimpaired physiological performance.

S. F. MARKHAM, in his Climate and Energy of Nations comments, "Man may be the highest product of the animal kingdom, the most intelligent and a superb triumph of evolution, but his control of body temperature is feeble compared to that of many animals. . . . Many animals can suffer a change of ten degrees in their body temperature without inconvenience, but man must keep his body temperature near 98.6° F or die." (8)

This critical interior temperature of man appears to be a focal phenomenon influencing man's development on this planet - and dictating the location of his origin. His origin had to occur at that place (or places) where, as an unclothed, naked animal, external weather conditions were such as to maintain man's internal temperature at the safe level.

Man's migration from his area of origin has finally covered the earth, but this has come about only because of man's inventions -- clothes, fire, and shelter. Strip him of the protection of his inventions and he dies.

The entire history of shelter engineering reveals an unremitting effort by mankind to provide itself with an indoor climate that would reproduce as nearly as possible the climate to which man is best adapted, i.e., the climate of his place of origin. Markham reports

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that research points to the neighborhood of the 70° F annual isotherm as the probable location of man's original habitat. (8)

IMPORTANCE OF BUILDING

Man's basic physiological equipment has not changed since man first appeared. Biological evolution seems to have stopped with man. The various races of mankind are evidence that the process of biological mutation in the direction of separate species began, but it was overtaken by a new type of mutation -- invention -- which first appeared in man.

Man was able to migrate, by means of his inventions of clothing, fire, shelter, land and water transport, etc., and so was able to mix. The gradual merging of the sub-species of man has been going on from prehistoric times, with the result that despite differences in skin color and other minor physiological characteristics, man is one species.

This has happened because man has elected to control his environment, instead of submitting to the natural gamble of survival by the mutation route. In short, man changes his environment, instead of changing to fit it.

It is this fact which gives the art of building its vast importance. It is essential to the survival of man; and lately the realization has been dawning that building is essential to help man realize his life potential.

LENGTH OF LIFE AND CLIMATE CONTROL

Evidence indicates that everyone at birth has a life potential of from 125 to 175 years. A few individuals have lived to 150 years, and beyond. However, most people die when less than half of their potential life span is complete, owing largely to the effects of hostile environments.

Tests on the skeletons of prehistoric men show their average age at death to have been 18 years. Man paid a penalty for migrating from his place of origin in a drastic shortening of his natural life expectancy. He migrated with the minimum of protection, open fires, inadequate clothing, and the crudest of shelter.

Effective climate controls have developed in relatively modern times. Throughout most of man's history the average person has had a very short life. Even in ancient Rome, the average length of life was only 33 years.

Where data are available, they tend to confirm common experience that life expectancy increases as the technological level rises, permitting more effective control over our environment. For example, life expectancy in the United States has increased from 66 to 70 years between 1940 and 1960.

Environmental control is very largely control over the direct and indirect effects of solar radiation. Building is one of the most common instruments used.

FUNCTION OF BUILDING

Building has the function of taking the load of the frequently hostile natural environment off the human body. While the body can accommodate itself to a range of fluctuations in the external environment, its limits of accommodation are fixed; and above and below them collapse and even death follow. Moreover, the range in which man can operate efficiently and maintain health over long periods of time, that is, the optimum range, is very much narrower than the total range which man can accept. It is the function of building to provide this optimum range.[1]

This means, as Benjamin Handler pointed out, we have to "shift our perspective from the building, its parts and its installed equipment, to the environmental conditions created by them. The focus of attention becomes this environment, with the building and its components regarded as devices for the attainment of the environmental conditions required by those who live and perform their various tasks in it." (4)

ENVIRONMENT AND MAN

1. The effect of seasonal climatic variations on physical activity in the temperate zone.

Studies by Ellsworth Huntington of Yale University (5) show that excessive dryness of indoor winter atmospheres (which are drier than that of the majority of deserts), produces a drop in physical activity. As the outside air warms up, and windows can be opened to counteract the inside lack of humidity, human activity increases to a peak in June, and then drops under the influence of the excessive heat of summer. As the summer wanes, human activity resumes its rise to a peak in the autumn, and with onset of winter begins a decline to a low in February. With proper indoor climatic control, these wide variations would not occur.

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[1] Dr. Hardy in his paper, Thermal Effects of Solar Radiation in Man (p. 19), shows the total range which man can accept without death quickly following; but man pays a penalty for operating continuously outside the optimum range even for very small departures. This penalty is a speeding up of the aging process. Towards the limits of the total range, clinical evidences of accelerated aging become obvious in such ways as tissue breakdown, capillary ruptures and impairment of circulation, heart muscle deterioration, and hypoxia (failure to deliver enough oxygen to the brain).

Clinical evidences of accelerated aging for small departures from optimum conditions are less obvious. The effects may take years to accumulate to a detectable point. However, their occurrence is supported by the fact that mortality tables for the United States and Western Europe now show a life expectancy barely one-half the genetic potential. In environments with a very low technological level, such as parts of Asia, life expectancy drops to about one-sixth of the genetic potential.

Huntington's studies show a different effect of seasonal variations on mental activity. Here the peak occurs in March, with a minor peak in November, illustrating that a lower ambient temperature is desirable for mental work, as contrasted with physical. That is, an indoor climate favorable for academic or office work is not necessarily the same as that which promotes physical activity.

2. The effect of temperature.

Huntington's study of 300 men in two Connecticut factories over a period of three years shows that human activity declines at both low and high temperatures and reaches a maximum at between 59° and 70° F for physical work in the temperate zone. The optimum temperature becomes higher for more southerly climates. However, the variation in the optimum is slight -- not more than 10° to 15° F compared with variations in mean temperatures of the places in question.

3. The effect of humidity.

According to Huntington's findings, humidity does not seem to be responsible for work fluctuations except as it is influenced by temperature. His findings show a diminution of work in dry weather, which has a bearing on the low level of the curve of human energy in winter. At that season the air in our space enclosures ought to have a humidity of 60% or 65%, but most of the time it is only 20% or 30%. On very cold days the percentage is still lower. For instance, if the outside air is 14° F and has all the moisture it can hold, which is usually not the case, its relative humidity, when warmed to 70° F will be only 12%. The extreme aridity has a marked debilitating effect. It dries up the mucous membranes and greatly increases susceptibility to colds. It is one of the most important factors in the high death rates for February and March.

4. The effect of light.

Studies by Huntington of the same 300 men in two Connecticut factories, who worked mainly in natural light, show that the increasing natural light available from the end of January to the end of May increased work output at a faster rate than could be attributed to the rising temperature and more favorable humidity conditions alone. After May, as adequate natural light was available through the summer, the effect on work output was largely the combined result of temperature and humidity.

With electric light, the situation is a little more complicated, particularly in view of the increased lighting levels now being recommended, although these new levels are far lower than the statistically most frequent daylight level of 3700 foot-candles (New York City).

Electric light differs most from daylight in relative percentage of infrared radiation. Discomfort caused by infrared from incandescent lamps is definitely felt at a horizontal illumination level of 125 foot-candles, and at about 500 foot-candles with fluorescent lighting. At such levels the rise in exposed white skin temperatures, in low ceiling interiors, is about 7° F, in a still atmosphere. At such levels the proportion of infrared is similar to that from a daylight level of 900 foot-candles.

Indoors, with an ambient temperature of 70° F, or higher, the addition of 7° F on local skin regions may reduce the rate of skin-to-air transfer (although it favors more rapid perspiration), as relatively high humidity conditions, which are probable in the summer, may occur. Then the individual will be uncomfortable, and his work rate will drop.

5. The effect of uniformity.

Where the direct and indirect effects of solar radiation produce a uniform, monotonous climate, the energies of men drop to a low ebb. For these regions the evidence is very clear. When any climatic condition is maintained steadily, a decline in men's energies and in physical well-being takes place.

A moderate change of temperature, humidity, air movement, and light away from the optimum, and then back again, checks this decline. It seems to be a law of organic life that variable external stimuli are better than uniformity. Where only one factor can be varied, it should be the one with the largest tonic effect -- temperature.

6. The effect of static atmospheric charge.

Very little is yet known about this, other than that a positive charge has deleterious effects on health and a negative charge has beneficial effects. The kind of a day on which we feel good to be alive is the kind of day on which the atmosphere is rich in negatively-charged ions.

7. The effect of air movement.

There is a scarcity of helpful data on the cooling effect of moving air on the human body. The particular clothing people may be wearing is a modifying factor in connection with all the effects of solar radiation. Economics requires that the development of the optimum indoor climate be accompanied by the development of the kind of clothing which will most effectively cooperate with this optimum indoor climate and which will permit the wearer to gain the maximum benefits in vigor, health, and happiness.

Some air movement is necessary in order to evaporate body fluids fast enough; if the components of the indoor climate are properly balanced, and appropriate clothing is worn, this rate should apparently cycle around 2 miles per hour. Too fast an air movement, such as 8 miles per hour, evaporates the body fluids too fast; but again, specific figures for actual cases depend upon the clothing worn, and the balance between the other climatic components.

ENVIRONMENT AND THE BODY

All of these direct and indirect effects of environment or solar radiation -- the seasons, temperature, humidity, light, uniform conditions, atmospheric static charge, and air movement -- directly influence the energy, health, safety, and longevity of people. Their interrelations are complex, but we are beginning to understand some of their aspects. It should be noted that these effects are, overall, at least as large percentagewise as the profit margin on which business operates. The design of buildings to provide an unimpaired physiological performance zone for people could greatly improve our national prosperity, as well as health.

Our environment is a composite structure, formed of many distinct, yet interacting, elements, which are actually complete environments in themselves. We are here concerned with only a portion of the entire spectrum of environmental effects - those which act directly and immediately upon the body, and which can be directly and immediately modified by building. These are illustrated in Fitch's diagram (3) reproduced in Figure 1.

These environments are paralleled by a specialization of body function which can be compared to a network of highways designed to handle two-way but highly specialized traffic between the body and the outside. These "highways" are distinct, coexistent, yet independent. For example, the respiratory system handles the essential commerce between the body and its atmospheric environment; the skin's main task is to maintain a "balance of trade" between the body and its thermal environment; the ear's job is to filter the sonic environment, etc. This is, of course, an oversimplification, for each of these systems has multiple functions. Thus the respiratory system provides our sense of smell, the skin protects the body against external attack, the ear also serves as a balancing mechanism. But this does not alter the basic principle involved.

The function of all these systems is to provide a constant equilibrium within the body by controlling the relationship between the body's external and internal environments. So characteristic is this constancy and so specialized are the processes which sustain it, that physiologists identify it as homeostasis.

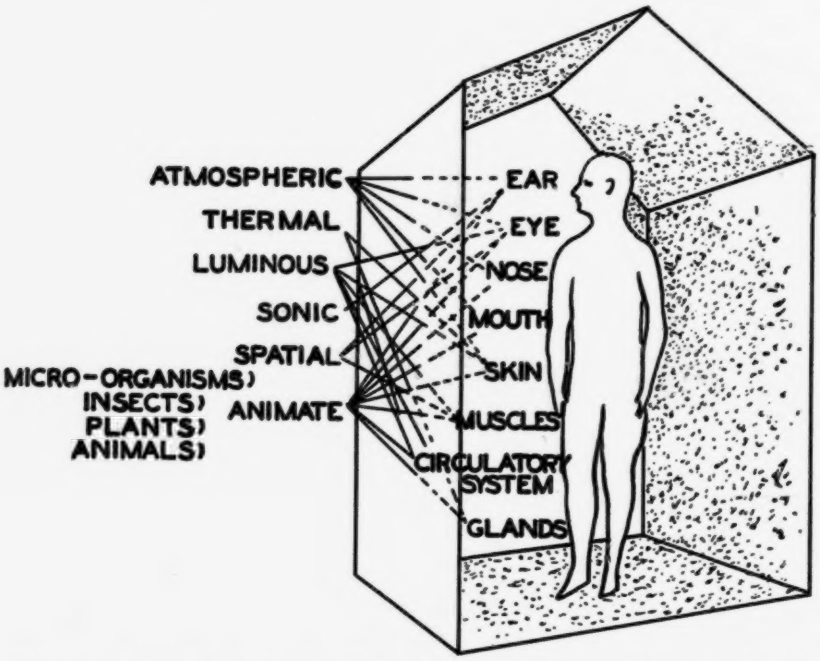

Figure 1 -- Modern building acts as a selective filter which takes the load of the natural environments off man's body and frees his energies for social productivity.

But the natural environments into which man has migrated are not always conducive to maintenance of this internal constancy. They fluctuate from being friendly to being actually hostile to the human body. Faced with this dangerous variability, man has evolved external instruments for regulating the relationship between his body's need of a mildly fluctuating environment, and the violent fluctuations of inconstant nature.

Building and clothing are the principal instruments. They both take the load of the natural environment off the body. Building, in fact, is only static clothing, pushed far enough away from the body to enclose a space in which an optimum climate can be generated. Such difference in function as does exist is that clothing protects an individual from the environment, and building protects an entire social operation or process. That building still performs this function imperfectly, is the reason for this Conference.

If out of this Conference can come a successful technique for the development of a nearly thermostable state in our buildings, it would be regarded as a milestone in the evolution of building.

COMPONENTS OF THE OPTIMUM CLIMATE

To sum up this all too brief review of some of the direct and indirect effects of solar radiation on people, these things are broadly true:

1. When people are clothed, the indoor temperature should be above 60° F, and below 76° F.
2. The relative humidity should be below 70% at the bottom of the temperature bracket, and above 40% at the top.
3. The air movement should be at least two miles per hour, and under eight.
4. The concentration of ions in the air should be negative and not positive.
5. More light than can be usually admitted by natural means should be provided.
6. The temperature and humidity should be slowly cycled opposite to each other, through a narrow range.

AIM OF THIS CONFERENCE

When we consider the means to provide these environmental elements within the ranges mentioned, two questions arise. Can we do this by building to take advantage of the assumed "free" heat, "free" ventilation, and "free" light of solar radiation? And if we can, can we do it as economically as we can do it if we do not rely on nature's so-called, free heat, free light, and so on?

The answer may depend upon the statistical frequency of situations where it is desirable to maximize the utilization of solar radiation compared to the frequency of buildings in which it is advantageous to minimize it. Such a study has not yet been conducted.

The conference discussion will be both stimulating and significant for future guidance on this subject of solar effects on building design.

I hope that we will learn more about the problem of designing buildings as a reflection of the need to enclose a specific optimum climate; and more about how to attain two of the basic objectives of building design;

1. To insulate the occupants of a building from those daily and seasonal variations of solar radiation, direct and indirect, which are unfavorable to people.
2. To develop an optimum thermostable state, with such controlled, cyclic fluctuations as may be needed to provide a zone of unimpaired physiological performance.

As Fitch pointed out, "the layman must judge building as he would any other tool - by its performance; and the criterion for judging building performance must necessarily be health, ... and social well-being. Does the building regulate the commerce between his body and its environment so as to promote optimum health? And, from the standpoint of society as a whole, do its buildings provide (that range of specific) interior climates which will guarantee maximum productivity to all its operations and processes?" (3)

When the answer to Fitch's questions can be "yes," the building industry and mankind will have taken a giant step forward.

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Solar Energy Data Applicable to Building Design

by Richard C. Jordan and Benjamin Y. H. Liu, University of Minnesota

Abstract: In building design, data on solar radiation for clear days or on average solar radiation for all days are generally adequate. The most commonly available data are the daily total radiation on a horizontal surface, provided by the U.S. Weather Bureau. Other solar radiation data are sparse, especially for the daily total radiation on vertical surfaces. Solar radiation for clear days can be estimated fairly accurately by theoretical means, but solar radiation for all days must be calculated on a long-term basis because of the variability in intensity on cloudy days. Average daily and hourly radiation on vertical or tilted surfaces can be estimated when the average daily radiation on a horizontal surface is known.

FOR MOST PURPOSES in building design -- such as the calculation of design cooling loads or the determination of the effect of solar radiation on the cost of operating the cooling and heating systems -- data on solar radiation during clear days or on the average solar radiation during all days are adequate. But problems such as the design of solar-heated houses (9, 10) require more detailed statistical analysis of the radiation data. This paper considers some of the basic characteristics of solar radiation and summarizes the present state of our knowledge about it in relation to building design.

JORDAN, RICHARD C. Professor and Head, Department of Mechanical Engineering, University of Minnesota; Chairman, Division of Engineering and Industrial Research, National Academy of Sciences-National Research Council; Vice President of Executive Committee, International Institute of Refrigeration (Paris); Past President, ASHRAE; member, American Society of Mechanical Engineers, American Association for the Advancement of Science, Association for Applied Solar Energy (council), and National Society of Professional Engineers. LIU, BENJAMIN Y. H. Assistant Professor, Department of Mechanical Engineering, University of Minnesota; member, Association for Applied Solar Energy.

NOTE: A complementary version of this paper is printed in the ASHRAE Journal, Vol. 4, No. 12, December 1962, pages 31-41, 66, under the title, "Analysis of Solar Energy Data Applicable to Building Design."

MEASURING SOLAR RADIATION

The pyrheliometer is used to measure solar radiation. The normal incidence pyrheliometer measures intensity of direct radiation at normal incidence; the 180° pyrheliometer measures the radiation incident on a horizontal surface and, when unobstructed, the total radiation (i.e., direct radiation and diffuse radiation). The sensing element of the instrument is enclosed within a glass envelope which is opaque to the long wave length radiation emitted by the atmosphere, so that only radiation of solar origin is measured.

For measuring the total radiation incident upon a horizontal surface, U.S. Weather Bureau stations and cooperative stations are maintained throughout the United States. Solar radiation data are published monthly by the U.S. Weather Bureau in Climatological Data, National Summary (18). These data are the daily total radiation on a horizontal surface only. The more detailed hourly radiation records may be obtained from the National Weather Records Center, Asheville, North Carolina.

Other solar radiation measurement data are sparse. The direct radiation at normal incidence is measured at a few stations. The U.S. Weather Bureau at Blue Hill, Massachusetts, has made an extensive series of measurements of particular interest to architects and engineers of the diffuse radiation on a horizontal surface and the total radiation on the four vertical surfaces facing the cardinal points of the compass (3, 4).

If no solar radiation measures are available, other meteorological data may be used to estimate the available solar radiation. The best such data are the percent possible sunshine data, reported by the U.S. Weather Bureau for some 174 stations, representing the ratio of the number of hours during which the sun is shining to the number of hours between sunrise and sunset. The method used in estimating solar radiation on a horizontal surface from these data is described in reference 6.

EXTRATERRESTRIAL SOLAR RADIATION

The solar radiation incident upon a surface of any orientation at the outer edge of the atmosphere is useful for a general understanding of the characteristics of solar radiation. The diural, seasonal, and latitudinal variations of this radiation can be accurately predicted. Computation involves the value of the solar constant, which is the intensity of solar radiation incident upon a surface (or the rate at which solar energy impinges upon a surface of unit area) in outer space, perpendicular to the sun's rays, at the mean distance of the earth from the sun. Measured by the Smithsonian Institution for over half a century, the solar constant has been assigned the following values (8), with a probable error of 2%: langley/min 2.00; Btu/hr/ft^2 442.4; kw/m^2 1.395; watt/ft^2 129.6; and kw-hr/day/ft^2 3.11.

The variation in distance between the earth and the sun causes a variation in intensity of radiation at normal incidence at the outer limit of the atmosphere. Thus, the incident radiation is 7% higher in December than in June and the winter and summer are milder in the Northern Hemisphere than in the Southern Hemisphere.

To calculate the radiation incident upon a surface of fixed orientation, it is necessary to consider the relative angular position of the sun. In engineering and architectural problems, however, it is more convenient to use the solar altitude angle (the angular elevation of the sun above the horizon) and the azimuth angle (the horizontal angle measured eastward from the north). A detailed tabulation of the altitude and azimuth angles as functions of the latitude, declination, and hour angles is found in reference 17.

A solarometer, with accompanying sun angle calculator, for determining the position of the sun at any hour of the day for any day of the year has been developed for use by architects and engineers by the Libbey-Owens-Ford Glass Company.

Examination of the extraterrestrial solar radiation curves gives qualitatively correct conclusions even when atmospheric effects are taken into consideration. The daily radiation incident upon the surface, integrated for a horizontal surface and the four vertical surfaces facing the cardinal points of the compass, shows the outstanding advantage offered by the south window. The radiation incident upon a south-facing vertical surface reaches a maximum during winter when heat is needed the most and decreases to a minimum during summer when heat is wanted least -- and even this unwanted radiation can be eliminated by use of overhangs and other shading devices. On the other hand, the radiation incident upon the east-, north-, and west-facing vertical surfaces all reach a maximum during the summer months when heat is undesirable.

SOLAR RADIATION DURING CLEAR DAYS

During clear days the constituent elements of the atmosphere which affect the transmission of solar radiation do not vary excessively, at least over non-industrial localities. Thus, it is permissible to consider an atmosphere containing average amounts of these constituent elements as standard. The direct radiation transmitted through this standard atmosphere may then be computed and used as an approximation in design calculations involving direct radiation during clear days whenever data are not available (16). However, if the atmosphere is heavily contaminated, these calculations for the standard atmosphere are not applicable.

For a surface not perpendicular to the sun's rays, the intensity of direct solar radiation (I_D) incident upon the surface is related to the direct radiation at normal incidence I_{Dn}) by the relation $I_D = I_{Dn} \cos \Theta$, where Θ is the angle of incidence of the solar rays.

Only that portion of the scattered solar radiation which travels downward arrives at the earth's surface as diffuse radiation. During clear days the diffuse radiation is usually a minor component of the total radiation received by the horizontal surface but during cloudy days all of the radiation received by the horizontal surface may be diffuse (12).

The total radiation incident upon horizontal and vertical surfaces during clear days, as recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers for use in cooling load calculations, can be found in the ASHRAE Guide (1,15). For a vertical surface, the diffuse radiation includes not only the diffuse radiation from the sky but also the diffuse solar radiation reflected from the ground at a ground reflectance of 10%. For ground surfaces with other than 10% reflectance, the following correction should be added to the vertical surface radiation: $1/2\ I_{Th}\ (\rho - 0.1)$, where I_{Th} = intensity of total radiation incident upon a horizontal surface and ρ = reflectance of ground for solar radiation.

AVERAGE DAILY TOTAL AND DIFFUSE RADIATION ON A HORIZONTAL SURFACE

Because of the extreme variability of cloudiness, the intensity of solar radiation received on the earth's surface under a cloudy sky is also extremely variable. The availability of solar energy during all days, therefore, can only be anticipated statistically from experimental data covering a long period of time.

To describe quantitatively the atmospheric conditions at a locality on a long-term basis, it is convenient to use an index $\overline{K}_T = \overline{H}/H_o$, where $\overline{H}$ = monthly average daily total radiation on a horizontal surface, Btu/day/ft^2 and H_o = average daily radiation on a horizontal surface at the outer edge of the atmosphere during the month, Btu/day/ft^2, representing the fraction of the extraterrestrial radiation transmitted through the atmosphere.

The arithmetical average, maximum, and minimum values of $\overline{K}_T$ for localities in the Continental United States are shown in Figure 1 for each of the 12 months. Only data of those localities with more than five-year records are used in obtaining the data. On a 12-month basis, the arithmetical average of $\overline{K}_T$ is equal to 0.552 for the Continental United States, and the maximum and minimum are 0.83 and 0.27 respectively.

The average curve in Figure 1 shows only a moderate seasonal variation, with the highest average value of $\overline{K}_T$ in July and the lowest in November. Part of this variation is due to change in solar declination and part is due to seasonal variation in atmospheric cloudiness. The large spread between the maximum and minimum curves of $\overline{K}_T$ shows that greatly different solar climates exist in the Continental United States. In general, localities in the Pacific Northwest, Great Lake Regions, and New England States have below average atmospheric transmission ($\overline{K}_T$) and those in the arid and semi-arid regions of the West and Southwest and the Rocky Mountain States have above average atmospheric transmission. Fritz and

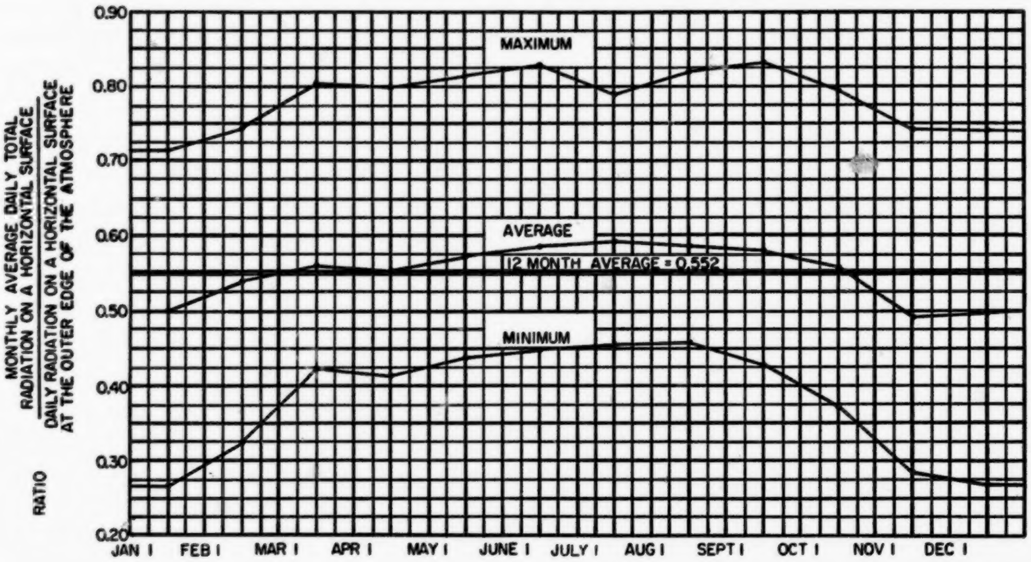

Figure 1 -- The arithmetic average, maximum, and minimum values of the atmospheric transmission coefficient for daily total radiation at solar radiation stations in the Continental United States.

MacDonald estimate the average daily radiation on a horizontal surface for January and July throughout the United States (5).

The available data on diffuse radiation are extremely sparse, but they indicate that, on a long-term basis, the diffuse radiation incident upon a horizontal surface is approximately 18% of the solar radiation incident upon a horizontal surface at the outer edge of the atmosphere (12).

AVERAGE DAILY TOTAL RADIATION ON VERTICAL SURFACES

The only available experimental radiation data for vertical surfaces covering an extended period of time are those obtained by the U.S. Weather Bureau at Blue Hill, Massachusetts. These data are shown in Figures 2 and 3. Also shown in these figures are the radiation values which these surfaces would receive if they were at the outer edge of the atmosphere. It should be noted that from the autumnal equinox to the vernal equinox, when the sun is always behind the north-facing vertical surface, the radiation received by a north-facing vertical surface on the earth is entirely diffuse radiation. Similarly, during the summer months, when the radiation incident upon the south-facing vertical surface at the outer edge of the atmosphere is small, the radiation incident upon the south-facing vertical surface on earth is also predominantly diffuse radiation. Therefore, the radiation incident upon the south-facing vertical

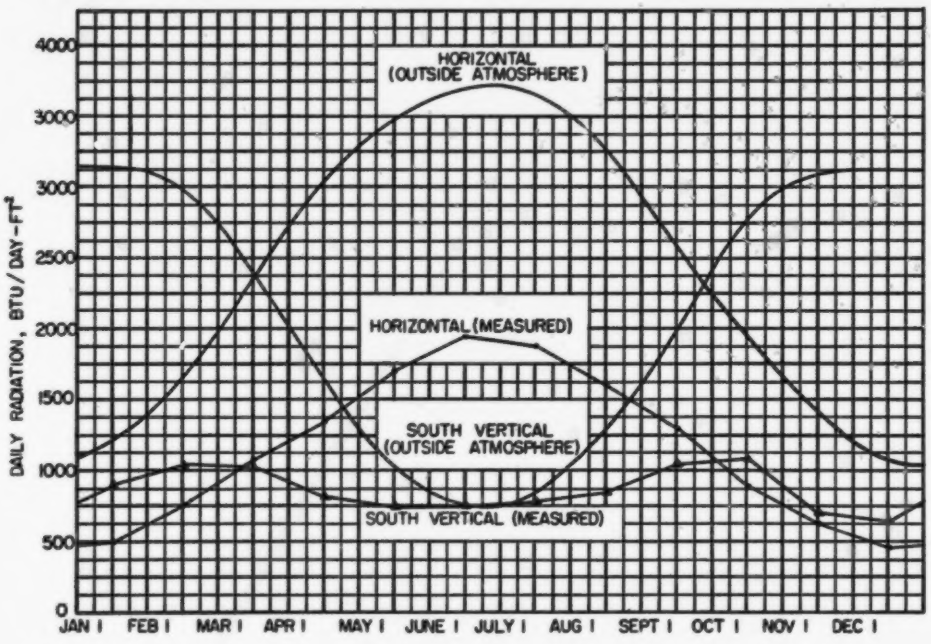

Figure 2 -- The average daily total radiation and the extraterrestrial daily radiation on a horizontal surface and a vertical surface facing south.

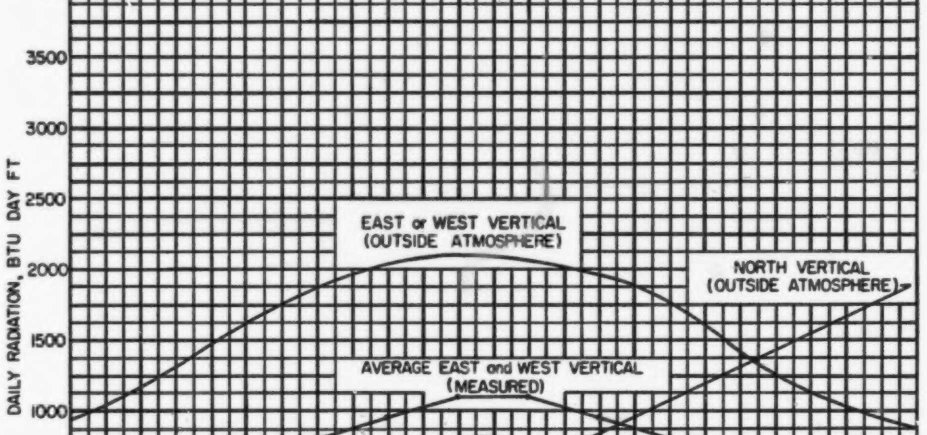

Figure 3 -- The average daily total radiation and the extraterrestrial daily radiation on vertical surfacing facing east, west, and north.

surface on earth may be equal to, or actually exceed, the radiation incident upon the similarly oriented surface at the outer edge of the atmosphere.

Since radiation data are not generally available for vertical or tilted surfaces, solar incidence on these surfaces must be estimated from the available data on a horizontal surface. Empirical and semi-theoretical methods have been developed for such estimation (2, 7, 11, 13).

AVERAGE HOURLY RADIATION ON HORIZONTAL AND TILTED SURFACES

The relationships shown in Figure 4, which is derived from experimental data for a large number of localities (12), may be used to estimate the hourly radiation on a horizontal surface from the daily radiation on a horizontal surface. It should be emphasized, however, that these relationships are correct only on a long-term average basis, since the extreme variability of cloudiness makes it necessary to gather long-term data to obtain such relationships.

Satisfactory methods have also been developed for estimating the average hourly radiation on tilted and vertical surfaces when the average hourly radiation on a horizontal surface is known (2, 7, 14).

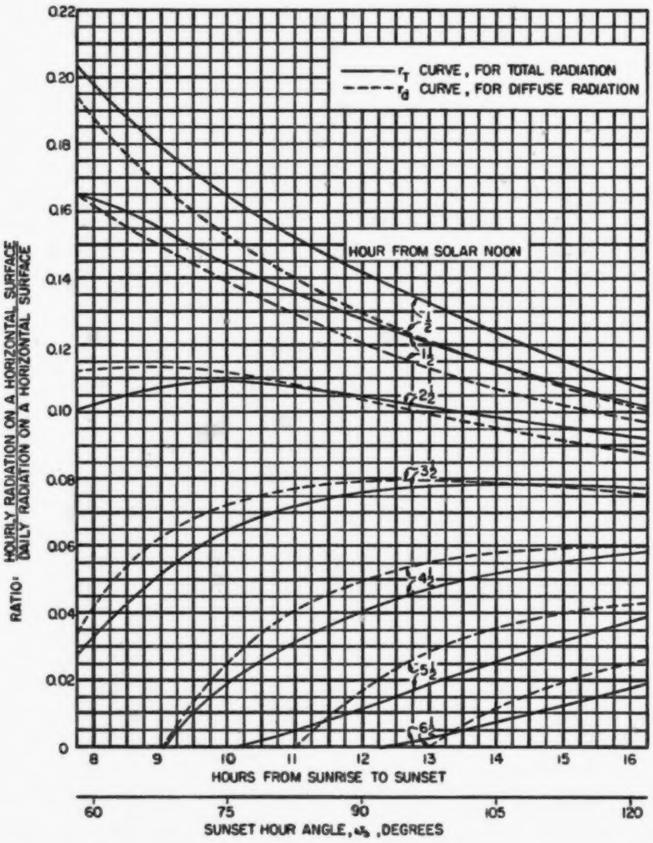

Figure 4 -- Relationships between hourly radiation and daily radiation on a horizontal surface.

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Thermal Effects of Solar Radiation in Man

by James D. Hardy, John B. Pierce Foundation Laboratory

Abstract: Changes in skin temperature caused by solar radiation depend not only on the optical properties of the skin but also on the thermal conductivity, density, and specific heat of the living skin. The heating of the skin by solar radiation is completely accounted for by simple heat flow theory and known physiologic changes in skin blood flow. The marked difference in reflectance in the visible and very near infrared spectral regions between darkly pigmented and white skin suggests that sunlight should have a much more stimulating effect on dark Negro skin than on white skin. Change in skin temperature is an important factor in perception of warmth or coolness, but skin temperature level also has a stimulating effect on skin blood flow. Pain and thermal injury may occur when solar heat radiation raises tissue temperatures into the danger zone, about 45° C. Therefore, man must shade himself from solar heat.

THROUGHOUT MAN'S HISTORY he has loved the sunlight. Ancient religions were devoted to the worship of the sun god and even as late as the Greco-Roman civilization the sun gods stood high in the divine hierarchy. Today, the sun has lost its divinity but none of its emotional importance. For the modern to stand in the sunlight is a "good thing" but to "remain in the shadows" is bad.

However, the sun is not necessarily a friend of man's physiology. From the very beginning of his existence, man has had to fight for survival against the searing rays of the sun. An evolutionary result is the very efficient physiologic temperature-regulating system in man, and the development of voluntary behavior patterns permitting him to explore and inhabit the earth almost without regard to sunshine. However, man still loves the sun and recent trends in architecture seem to be directed toward giving man his sunshine and yet reducing the hazards of exposure to solar radiation.

It is fitting to review briefly some of the effects of solar energy on man from a physiologic standpoint. There are two important actions of sunlight: photochemical and thermal. The photochemical action includes stimulation of the visual receptors of the eyes and the photochemical reactions in the skin associated with erythema

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production, pigment elaboration, and anti-ricketic effects. The thermal actions include stimulation of warmth sensation, changes in skin blood flow, and elevation of skin temperature to levels evoking pain and even thermal injury (2). Here it seems appropriate to select for discussion the thermal effects of solar energy on man. Many of these data have not reached building scientists.

Figure 1 outlines the framework for the material to be presented. The effective inputs of the environment into man are shown as being electrical, mechanical, thermal, and chemical energies. Solar radiation is concerned with the thermal and chemical energies (1). The thermal inputs give rise to local excitatory events evoking sensations first of warmth and then of pain. For weak stimuli, the local effects will include changes in skin blood flow and eliciting of sweating. For stronger stimuli, noxious stimulation which is associated with pain will cause local inflammation; reflex effects such as change of heart rate, respiration rate, glandular secretion; and states of nervous hyperexcitability at the spinal cord level.

In conscious man, the sensations give rise to reactions which are conditioned by the feeling state of the individual, cultural attitudes, and other higher functions which affect total bodily behavior. If pain should be involved, these reactions can, by virtue of nervous and hormonal connections with the other organs of the body, evoke still further noxious stimulation and pain. Such overall reactions are commonly seen when large bodies of military personnel are moved from a temperate to a tropical climate. It is the intention of this report to consider the effects of thermal stimulation in producing changes in skin temperature and the associated physiologic

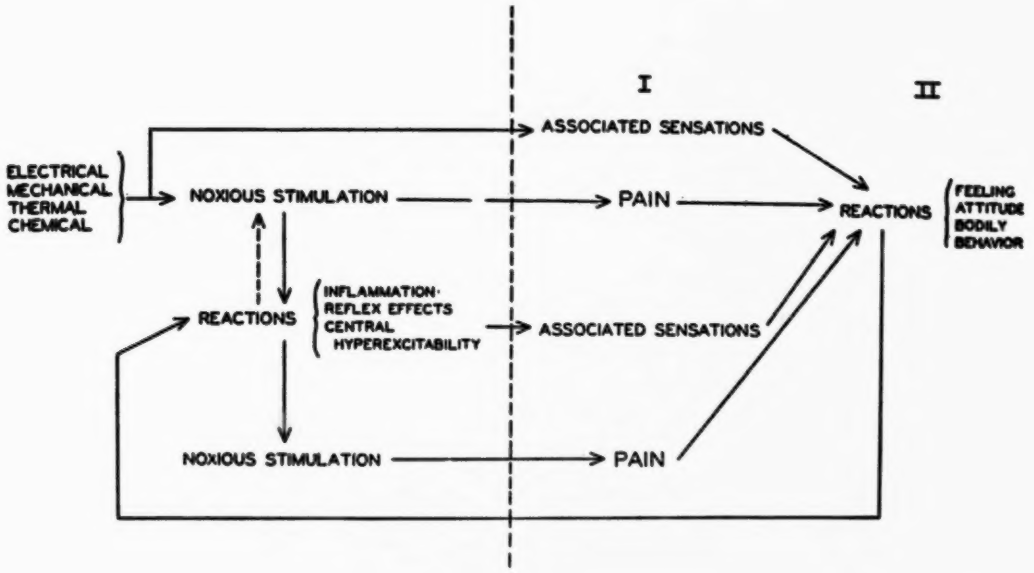
I
II
ASSOCIATED SENSATIONS
ELECTRICAL
MECHANICAL
THERMAL
CHEMICAL
NOXIOUS STIMULATION
PAIN
REACTIONS
FEELING
ATTITUDE
BODILY
BEHAVIOR
INFLAMMATION·
REFLEX EFFECTS
CENTRAL
HYPEREXCITABILITY
REACTIONS
ASSOCIATED SENSATIONS
NOXIOUS STIMULATION
PAIN

Figure 1 -- Conscious and unconscious response of man to environmental stimuli.

reactions. For this purpose, it is necessary to have a knowledge of the optical and thermal characteristics of the human skin.

OPTICAL PROPERTIES OF SKIN

The skin, being warmer than the environment, radiates to the environment and thus provides opportunity for studying spectral radiation from man's body as compared to radiation from the sun. Figure 2 illustrates the results of such studies. Two well-known important differences between solar radiation and the radiation from man's skin are at once apparent. First, the two emission curves lie in different portions of the electromagnetic spectrum which do not overlap appreciably. The sun's energy is contained largely between wave lengths 0.3μ and 2.8μ, much of the infrared having been filtered out by the water vapor and CO_2 in the earth's atmosphere. Secondly, the sun radiates 800 kcal/m^2/hr on a surface normal to the sun's rays, whereas the total radiation from the skin, which may be as much as 70% of the heat loss from the body, is in the neighborhood of 20 kcal/m^2/hr.

The emission curve for the skin shown in Figure 1 is based on the assumption that the human skin is a black body, in the spectral region between 4μ and 20μ, as shown experimentally to be the case. However, it is desirable to know the reflectance and transmittance of skin in the region where it interacts with sunlight. In order to study this problem, a goniometric spectrometer was developed so that excised skin could be illuminated with a narrow beam of monochromatic light and a measurement made of the reflected and transmitted energies. The scheme for this study is shown in Figure 3. The skin specimens were obtained from surgical operations and

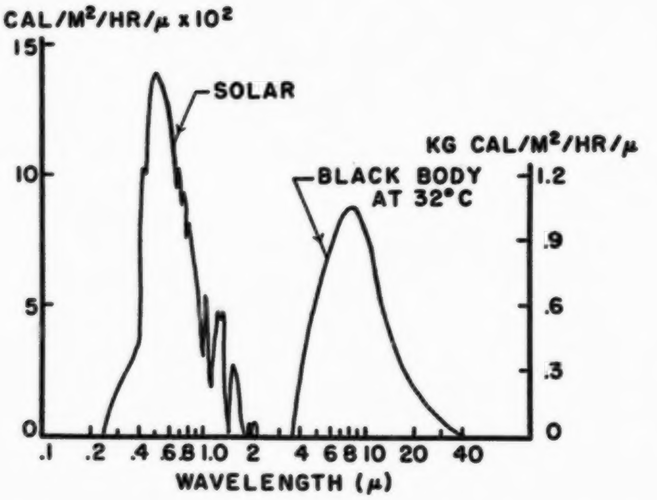

Figure 2 -- Spectral distribution of solar radiation (air mass = 1) and low temperature radiation from the human body.

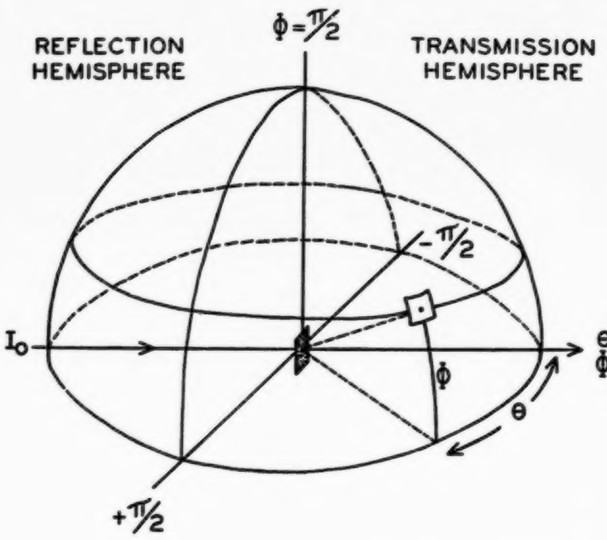

Figure 3 -- Experimental scheme for studying the scattering of monochromatic radiation. I_0 represents the incident beam normal to the skin specimen at the center of the hemisphere. The detector scans both in longitude (Θ) and in latitude (Φ).

were cut to the desired thickness with a Stadie microtome and mounted in the spectrometer at the center of the transmittance and reflectance hemispheres. The total diffusely transmitted and reflected energy was measured by scanning the detector over both hemispheres and integrating for each hemisphere. These sums, divided by the intensity of the incident beam I_0, give the values of reflectance and transmittance for a particular wave length.

The first question that can be answered is whether the skin obeys the Lambert cosine law for the near infrared and visible spectral regions. Curves for wave length 1.28μ show for both thin and thick specimens that the cosine law is indeed followed. Measurements at other wave lengths gave similar results. This validation makes it possible to study the reflectance of skin by simpler devices, such as the total reflecting hemisphere developed many years ago by W. W. Coblenz of the National Bureau of Standards.

Figure 4 shows the results of the studies by many authors of the reflectance of human skin, both white and Negro, from 0.4μ to 20μ. The similarity of these curves is at once apparent. The absorption bands are due to water vapor in the infrared and to hemoglobin absorption for the white skin in the visible. There is no appreciable difference between white and Negro skin for wave lengths longer than 2μ. However, the marked difference in reflectance in the visible and very near infrared suggests that the darkly pigmented skin will be heated by the sunlight to a greater extent than will white skin and thus the sunlight should have a much more stimulating effect on dark Negro skin than on white skin.

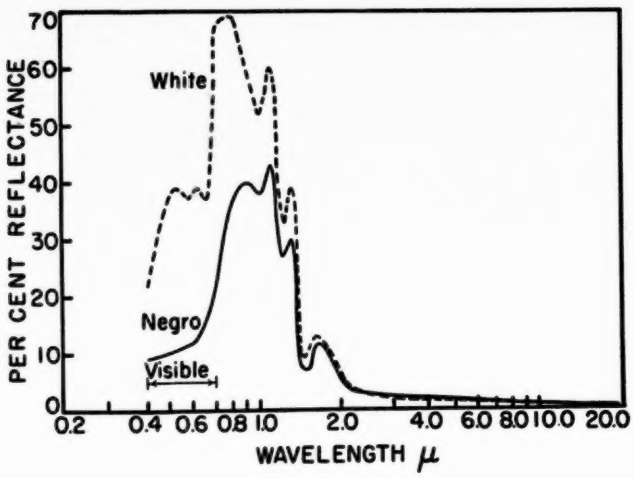

Figure 4 -- Average values of spectral reflectance of white and dark Negro skin.

The problem of transmittance is much more complex. In the first place, the scattered radiation does not follow Lambert's law, particularly for the infrared radiation, and for the most peripheral skin layers. As a result of this, the absorption coefficients for various skin layers differ considerably with wave length. This situation is clearly visualized in Figure 5.

It is seen that in the visible spectrum (curved lines) the usual law of transmittance (Beer's law) is not obeyed, whereas for the near infrared, the absorption coefficients are independent of thickness and thus Beer's law holds fairly well. As with the reflectance curves, the transmittance curves for Negro and white skin are practically identical for wave lengths longer than 1μ. The near infrared transmittance for a specimen of white skin shows that there is some slight penetration of visible and near infrared to depths of 1-2 mm below the skin's surface.

THERMAL CHARACTERISTICS OF SKIN

The changes in skin temperature caused by solar radiation depend not only upon the optical properties of the skin but also upon the thermal conductivity, density, and the specific heat of the living skin. With the development of a dependable method for measuring skin temperature before and during exposure to known intensities of radiation, it became feasible to apply the theory of heat flow to the problem of skin heating. This relationship leads to a parabolic

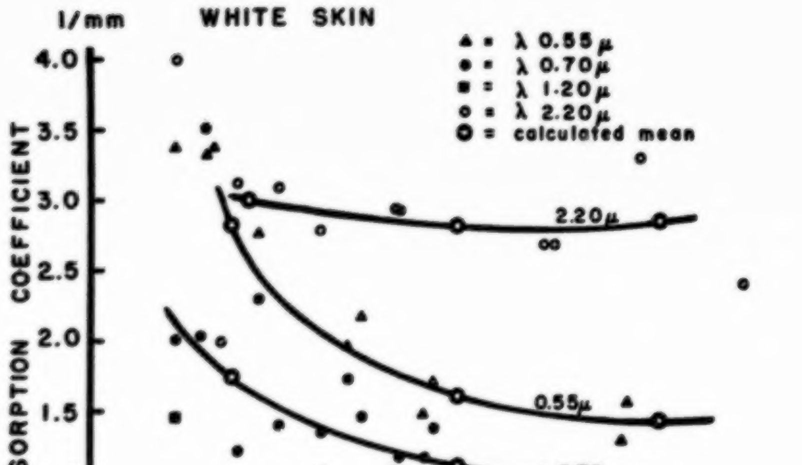

Figure 5 -- Absorption coefficients at four wave lengths for white skin as a function of thickness.

relationship between exposure time and skin temperature rise for non-penetrating radiation and can be expressed as follows:

$$T_s - T_o = \Delta T = \frac{2Qa\sqrt{t}}{\sqrt{\pi}\,K\rho c}, \quad \text{and} \quad K\rho c = \frac{1.13Q^2 t}{\Delta T^2}$$

In these equations,

T_s = Final skin temperature
T_o = Initial skin temperature
Q = Radiation intensity
t = Time in seconds
K = Thermal conductivity
ρ = Density
c = Specific heat
a = Absorptivity (0.94 for skin blackened with India ink)

The product $K\rho c$ is the physiologically important quantity which will determine the temperature elevation of the skin or other tissue upon exposure to non-penetrating radiation. For example the heating effects caused by irradiating the blackened surface of specimens of human skin, fat, and bone show differences due entirely to the differences in the $K\rho c$ products. Fatty tissue, because of its relatively low specific heat, is heated considerably more rapidly than either moist skin or bone. From such an experiment, the $K\rho c$ values can be determined by plotting ΔT^2 against $1.13Q^2t$, as shown in Figure 6. The lines in the figure are straight and pass through the origin,

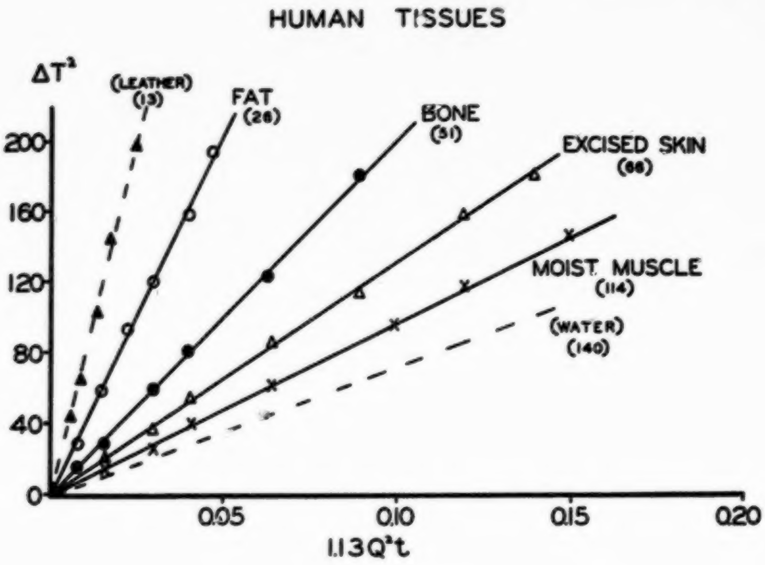

Figure 6 -- Thermal inertia for fat, bone, moist muscle, and excised skin, as compared with thermal inertia for leather and water. $K\rho c$ values are shown in parentheses for each specimen.

as would be expected from theory. The figures in parentheses at the top of each curve are the values for the $K\rho c$ product for the particular specimen (x 10^{-5}). A comparison of leather and water with body tissues suggests that the thermal inertia values depend to a large extent on their water content.

As might be expected, living tissues do not conform strictly to the simple mathematical formula outlined above, as shown by a comparison of excised skin with living skin, with and without its normal blood flow. For short exposure times, the $K\rho c$ of normal skin is the same as that in which the blood flow has been occluded and the excised skin heats more rapidly because of the unavoidable dehydration which occurs post-mortem. However, for longer exposures to thermal radiation, skin blood flow increases through vasodilatation and serves to cool the skin. This action can be observed as early as 20 seconds after the beginning of an exposure but may be delayed for as long as several minutes, depending upon the initial state of the skin blood vessels. For the first 20 seconds of irradiation, the skin can be considered to have a $K\rho c$ value of 110-130 x 10^{-5} cal^{2}/cm^{4}/sec/° C^{2}.

The heating of the skin due to solar radiation involves all of the optical and thermal properties of the skin which have been discussed. In Figure 7 are shown the experimental curves of skin heating by solar radiation. The studies were made on clear summer days in Philadelphia. It is seen that the white and light brown Negro skins are heated least and to about the same extent. Some of the white subjects had sun-tanned skins and others did not. The dark Negro

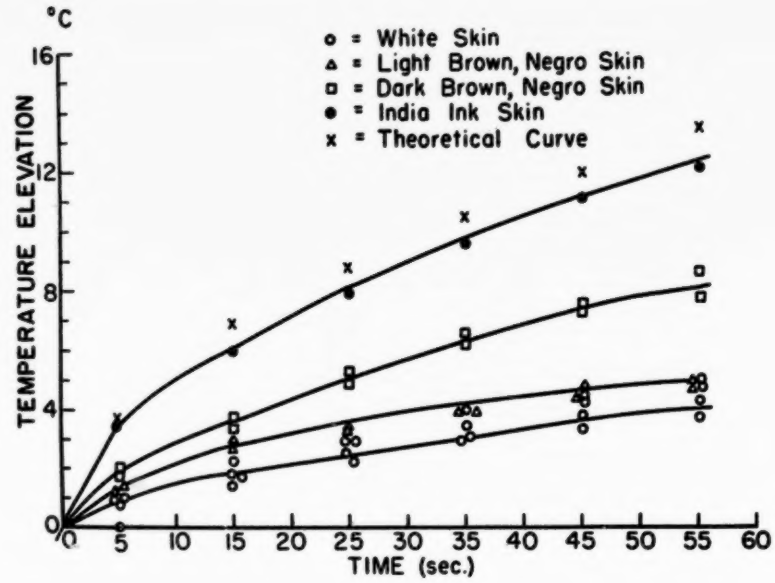

Figure 7 -- Heating of the skin by solar radiation: comparison of white skin, light brown Negro skin, dark brown Negro skin, India ink skin, and a theoretical curve.

skin is heated about twice as rapidly as the very white skin, a result which is not unexpected when considering the high absorption of the Negro skin for visible radiation. Skin blackened with India ink is heated most rapidly, this heating, of course, being independent of natural skin pigments. The rate of heating predicted from the equation is marked by x's in Figure 7, using a Kρc value of 100 x 10^{-5} cal^2/cm^4/sec/° C^2. From this it can be concluded that the heating of the skin by solar radiation is completely accounted for by simple heat flow theory and known physiologic changes in skin blood flow.

SENSATIONS OF WARMTH

If careful measurements are made of the skin temperature while the subject is sitting quietly in a darkened room at a comfortable and neutral temperature, and if the subject is asked to introspect and report upon his thermal sensations at specific intervals, say every 10 or 15 seconds, it will be found that the skin temperature fluctuates spontaneously. These fluctuations are small, usually less than 0.2° C, but it will be found that the subject continually reports thermal sensations other than neutral which are related to these small changes. Also, in such a situation, if a weak infrared radiation is projected onto the skin so as to raise the skin temperature 0.4° - 0.5° C, definite sensations of warmth will be reported. An analysis of these data is shown in Figure 8, in which the reports of

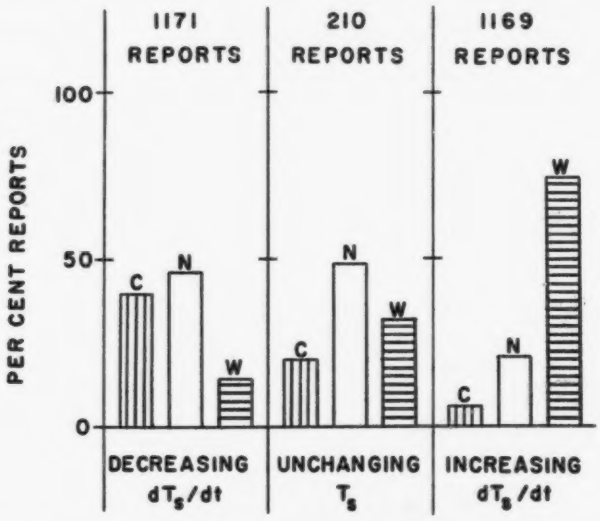

Figure 8 -- Relation of skin temperature change to thermal sensation in a thermally neutral environment, categorized as to whether skin temperature is decreasing, unchanging, or increasing. N = neutral; C = cold; W = warm.

sensation are categorized as to whether the skin temperature is decreasing, unchanging, or increasing. When there is no change in skin temperature, the subjects report with about equal frequency "slight warmth," "slight coolness," and "neutral."

This situation differs markedly from that for vision, hearing, and other special senses. In the dark, one sees nothing, and in a proper anechoic room one hears only his own blood pulsing in his inner ear, but in a thermally neutral environment one continues to feel thermal sensations. This result is not surprising since it is known that the temperature receptors in the skin are in continuous activity and change their activity only when the skin temperature changes. From Figure 8 it is seen that, when the skin temperature falls slightly, there is a marked diminution in the reports of warmth but an increase in the reports of cool and neutral. When the skin temperature is increased slightly, there is a marked increase in warmth reports, and a marked diminution in cold and neutral reports. The act of changing the skin temperature is thus an important factor in the perception of warmth or coolness but skin temperature level also has a stimulating effect to a lesser degree.

In examining the effects of solar radiation in stimulating sensations of warmth, one would expect, based on the above evidence, that sunlight will stimulate the Negro much more easily than the white man. This is borne out by experimental results but not to the extent that might have been anticipated. In experiments with sunlight, when allowance is made for the fact that the white subjects were about 25% more sensitive to heat than the Negro subjects, the Negroes were found to be only about 15% more sensitive to solar radiation than were the white subjects. As skin pigment has no effect on the heat loss from the skin surface, only in sunlight can this pigment be considered to play a significant role in the exchange of body heat. The temperature changes evoking sensations of warmth are small, being about 0.001° C/sec. However, the levels of skin temperature evoking continuous sensations of warmth or coolness differ from the neutral by 2° - 3° C. This difference between the phasic and continuous response to temperature has not as yet been thoroughly studied.

THE THERMAL INJURY PROBLEM

When an individual exposes himself to the summer sun while taking a sunbath, usually there is no immediate ill effect. However, dangerous sunburns are not uncommon in the tropic and semitropic zones. When such sunburns occur, it is unclear as to whether the damage has been due to ultraviolet radiation or thermal radiation, or perhaps both. One way to test the matter is to expose an individual in the laboratory to thermal radiation of about the same intensity as that of sunlight. In Figure 9 is shown a temperature tracing from the forehead of a subject while being irradiated with 26 $mcal/sec/cm^2$ of thermal radiation, which is somewhat less than the intensity of bright sunlight. The subject's skin is blackened to insure maximal absorption, a situation which is not dissimilar, as we have seen before, to the darkly pigmented individual. The skin temperature is raised very rapidly from a normal value of about 32° C to between 40° C and 42° C. As the exposure continues, pain is perceived in about half an hour and for a while the pain alternates with sensations of heat. At the end of about 38 minutes continuous pain supervenes. Fortunately for the sunbather, there are heat loss avenues which keeps his skin temperature below that shown in the figure. However, indoors, behind a clear glass, local skin temperature level may not be so far from that shown in Figure 9, and thus the individuals may be intensely uncomfortable.

Pain is the signal for tissue damage and this has been established experimentally for man. During World War II, the Army was much concerned with the problem of how to protect soldiers against fire and one of the researches was that of Moritz, a pathologist, and Henriques, a physicist, who showed that burning of the skin could be characterized by a first order rate reaction equation. Figure 10 shows the results of Moritz and Henriques, who plotted the thresholds for first- and second-degree burns as a function of skin temperature and duration of the hypothermic exposure. It is seen that skin temperatures lower than 42° - 43° C did not produce a burn within the time studied. Henriques applied the reaction rate equation to his data and, as shown by the dashed lines and the solid lines going through the experimental points, he found an excellent correlation between burn production and reaction rate.

Pain also has a threshold near 45° C, and thermal pain increases in the same way as does the production of tissue damage. Henriques concluded that the most plausible explanation for the producing of

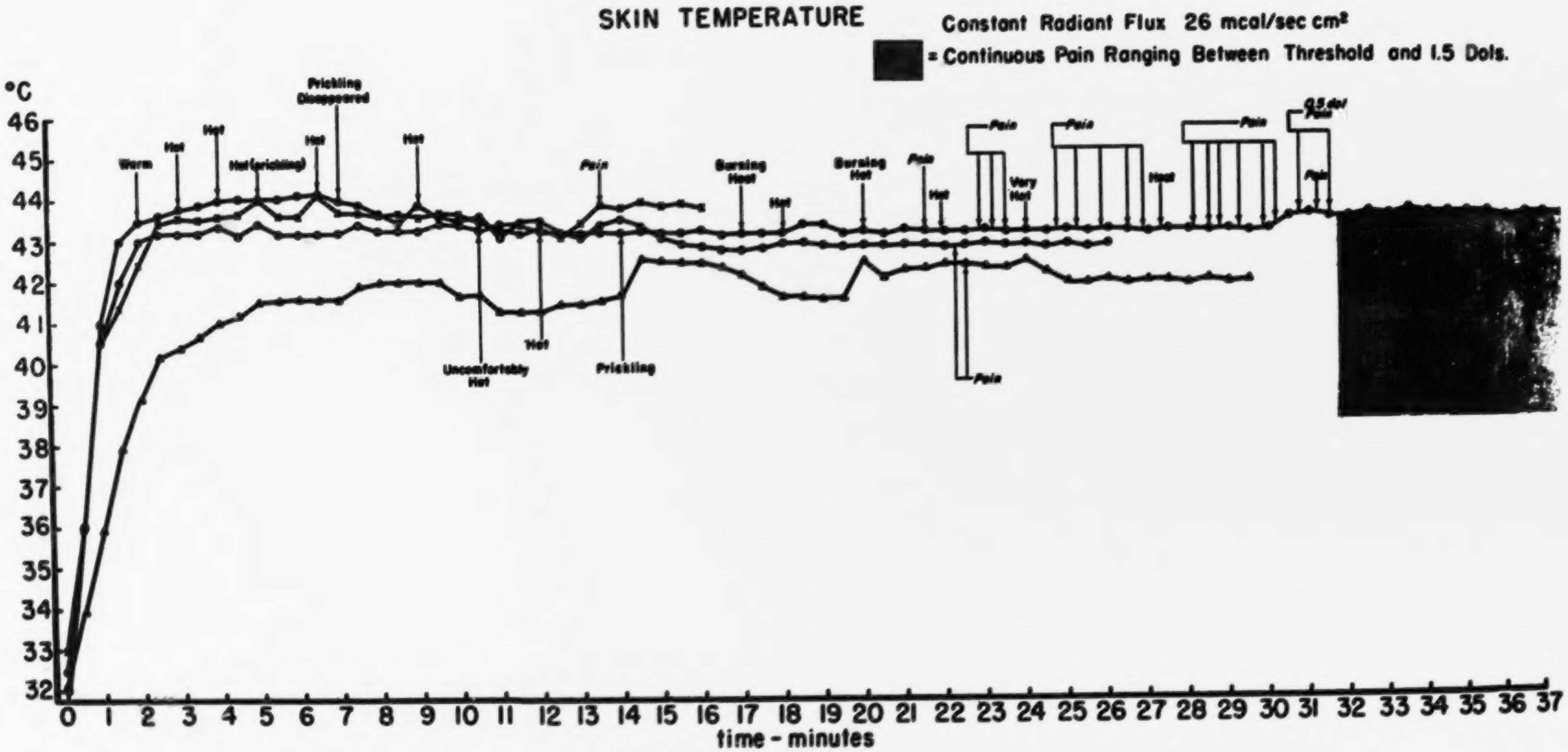

Figure 9 -- Skin temperature and reports of sensation during irradiation at the level of noon summer sunlight.

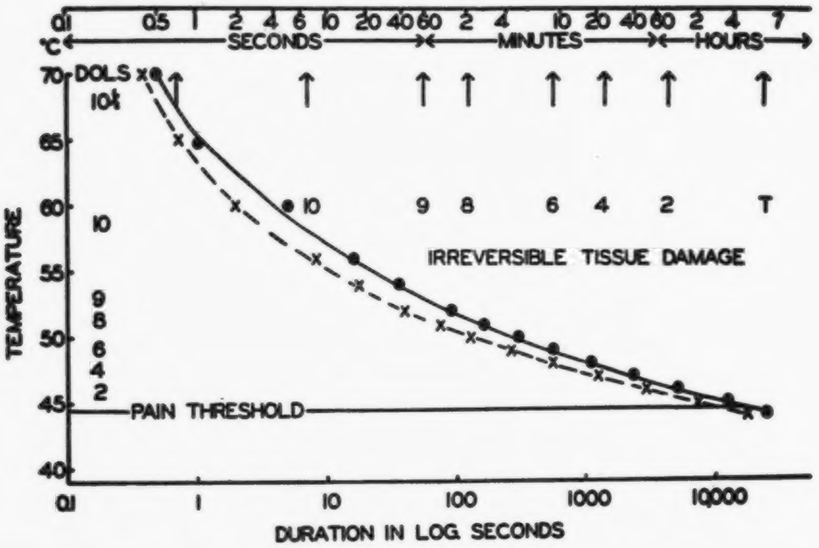

Figure 10 -- Relationship of skin temperature, duration of elevated skin temperature, and production of tissue damage. Pain intensity for various skin temperatures is noted for comparison (11 dols = maximum pain). - - - = threshold for transient erythema; ——— = threshold for "transepidermal necrosis."

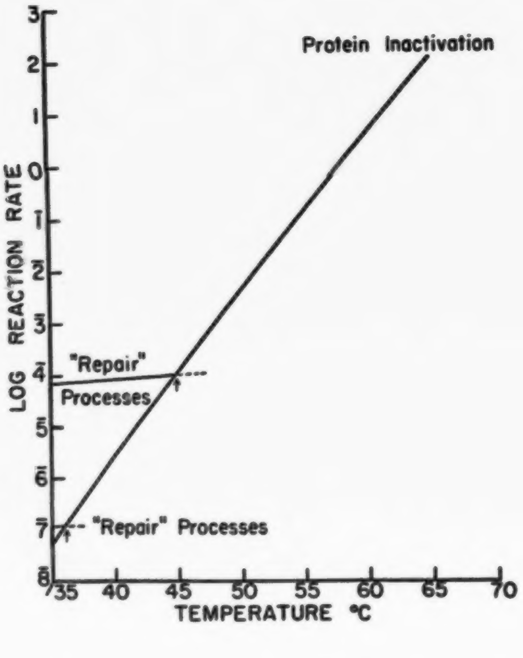

Figure 11 -- Comparison of cellular repair rates and protein inactivation as a function of tissue temperature.

skin burns is that the elevated temperatures gradually denature vital cellular proteins and thus cause the death of the skin cells. The arrows in Figure 10 denote the length of time that the skin can support a pain of a given density (11 dols = maximum pain) as observed experimentally. It seems likely that pain due to heat is related to thermal inactivation of cellular proteins in the same way as burning the skin, and that the production of pain is thus associated with the rate of denaturation of cellular proteins.

On this basis one must expect the skin proteins to be continually broken down, but they are rapidly repaired by the metabolic process of the cells. Cellular processes, however, increase their rate of activity very slowly with temperature, whereas the rate of protein inactivation increases very rapidly. Thus as shown in Figure 11, there will undoubtedly be a temperature at which the rate of protein inactivation will exceed the ability of the cells to repair. This temperature is both the pain threshold and the tissue damage threshold.

It is remarkable that this temperature is so near the normal temperature for man, 37° C, providing only 6° - 8° C margin between normal temperature and a lethal temperature. The fact that sunlight can raise the tissue temperatures into the danger zone makes it imperative that man shield himself from this heat.

Many of these considerations have been taken into account by those developing architectural structures involving large glass areas. Many years ago the large picture window was installed and immediately suitable drapes were arranged to shield the occupants from the effects of sunlight. More recent developments have included installations of heat-absorbing glass which greatly reduces the thermal load on the building occupant.

Further developments are perhaps still in the future. For example, it might be possible to provide a room with heat loss changes which would exactly compensate for the heat gain from the sun. This situation would more closely simulate the outdoors and perhaps give the feeling of being outdoors. If, when the sun shines into a room, a radiant or convective cooling system could be activated to compensate for the heat gain, the overall effect might be very pleasant indeed. From the physiological point of view, the introduction of tinted heat-absorbing glasses for clear plate glass is indeed a step in the right direction.

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Open Forum Discussion

Moderator: Leander Economides, Voorhees Walker Smith Smith & Haines

Panel Members: Messrs. Hardy, Liu, and Logan

Mr. Economides: Man, through the control of his environment, could conceivably, in time, influence his own evolutionary development and perhaps create conditions for his survival but will be dependent upon the maintenance of the environment which he himself has created. May we have a comment on this thought?

Mr. Logan: I don't think that the maintenance of an environment that is optimum for man would diminish the limits in which he could operate. All that providing the optimum environment will do for man is to let him realize the full potential of his genetic heritage. If he is forced by circumstances to accept less than the optimum, he pays the penalty of a shortened life, as he is now doing all over the world.

Interfering with man's genetic equipment so as to change his fundamental characteristics is an entirely different matter. Most mutations are harmful. The possibility of developing favorable mutation is remote. One can only speculate on this.

Mr. Economides: Professor Liu, you have indicated that the solar intensity at the earth's surface is dependent upon many of the atmospheric conditions which prevail in any locality. Can you foresee the artificial introduction of some elements in the atmosphere to limit and control the incident radiation in particular localities?

Mr. Liu: Whether there is a practical means of controlling atmospheric conditions so that we can markedly change the climate that we live in is somewhat questionable. I understand that the Weather Bureau is working on this. For example, artificial rainfall has been made, and this could be extremely important.

John M. Evans, Florida Architect magazine: In London, at the School of Hygiene and Tropical Medicine, a comment was made that tropical man -- and even white man -- by natural selection seems to eliminate the large blonde, blue-eyed Nordic type and makes the thin wiry brunette the norm. Would you comment on this, particularly on body size, and effect of heat transfer by evaporation?

Mr. Hardy: After studying the matter of pigment, which seems to me to be one of the factors separating the temperate climate dweller from the tropical climate dweller, I could not conclude that pigment served a useful function in temperatural adjustment. Pigment insures that the individual will be heated up faster, and on the basis of tests, it is clear that the dark-skinned man feels warmth from the sun more than the white man does. Perhaps this stimulates him to avoid excess solar heat a little more than the thin-skinned white man.

As far as body size and evaporation are concerned, it's certainly true that the individual who has the bigger surface area to volume ratio can get rid of more sweat than the individual who is rounder. However, whether or not this does, or has, played any significant role in the evolution of man seems to me questionable. I have an idea that considerations other than the surface area to weight ratio have governed the migration of groups of men from one area to the other.

John M. Evans: Does the metabolism of the person in relationship to his larger body size give him more sweat glands and give him better ability to be a more efficient heat exchanger?

Mr. Hardy: Evidence supports the idea that the metabolism is produced as a function of the lean body weight and that the heat loss is the function of the overall surface area; thus, it is the surface area to weight ratio that is really of interest. If one attempts to represent man as a heat exchanger (for example, as a group of cylinders), then it is clear that the man who is tall and thin has an advantage in terms of surface area to weight ratio and in adjustment to heat.

Sylvester H. Walter, E. I. duPont de Nemours & Co., Inc.: Today the trend in industrial building design is to eliminate all natural light and ventilation and to provide artificial light and climate by mechanical means. Please comment on how this affects industrial employees' work efficiency, health, and longevity?

Mr. Logan: Such records as are available are in favor of complete control of the indoor climate artifically. There are psychological factors that are not clearly taped out yet. One of them is the need for people to be able to establish their orientation with respect to external conditions at all times, which means that they must have optical contact with the outside; therefore, it seems desirable to always provide vision strips for this purpose. However, there is no certainty at the present time that this is actually essential -- just a belief that it is. Outside of this apparent need for optical contact with the exterior, the statistics are all in favor of a controlled interior climate of the proper type. This results in more uniform production by the workers, greater production, less errors, fewer accidents, the accumulation of a lower state of fatigue at the end of the day's work, and a slower rate of aging.

J. H. Segal, NASA: What can be done to control or reduce high temperature (80° to 95° F.) caused by solar radiation in offices with south and southwest exposures during the early spring and fall? For example, an existing multi-story office building of contemporary design in the Washington, D. C., area provides a winter-summer hook-up, an extensive exterior fixed glass area, venetian blinds, modular fluorescent lighting, and controlled air conditioning, heat, and ventilating systems.

Mr. Jaros: The obvious answer would be to properly compute the cooling load resulting from those conditions and provide for it in the air conditioning design. In southern exposures in midsummer, there is another answer -- the use of hanging balconies, or horizontal louver banks, set outside of the glass to produce a large amount of shade. But, in the spring and fall, particularly in October or thereabouts, you do have the problem of the low sun and this is something you have to take into account in the design. In our own practice, we figure more cooling load on southern windows in October than in July or August and we provide for it in the quantities of cooling.

Mr. Economides: Since the building is equipped with refrigeration and air conditioning facilities, the problem seems to occur in the spring and fall. The only thing to do is operate the refrigeration plant and the air conditioning system and use the venetian blinds for shading purposes.

Clayford T. Grimm, Zonolite Company: Professor Liu, you described a residence in which the power input in winter was directly correlated to solar radiation. Would you describe the type of construction? I rather imagine that thermal inertia had a lot to do with this correlation.

Mr. Liu: During these tests, we have been selecting data showing that the previous days had about the same outside temperature as the days shown in the data presented. The house has a chance to reshift thermal equilibrium with its environment and thereby the effect of thermal inertia becomes reduced. Of course, it would be impossible to reduce completely the effect of thermal inertia. In this case, we feel that the effects shown in the graphs are primarily due to solar radiation and not due to thermal inertia.

T. H. Markus, Pilkington Brothers, Ltd.: In calculations of thermal comfort it has been pointed out that radiation exchange between a person and a window has to be taken into account. In summer when there is transmitted short-wave solar radiation, there is likely to be heat gain to the body; and in winter when the surface temperature of the glass is low and there is long-wave radiation exchange between the body and glass, there is likely to be heat loss. There can, of course, be conditions when both processes occur simultaneously. In thermal comfort work, is some differentiation made between equivalent quantities of radiation gain or loss according to the wave length at which they take place?

Mr. Hardy: One would certainly have to take into account the differences in reflectivity of skin and clothing for the different wave lengths of radiation to get a good estimate of the total heat load. The easiest way to do this would be to measure some skin and clothing temperatures of people who are in this situation. This may be rather important, because although the individual under a complex radiant heat load may be quite comfortable, he may have local cooling or heating to a degree which will alter skin temperature locally sufficiently to induce disorders which, over a period of time, could become troublesome. Therefore, my own approach would be to look at the skin temperature distribution over the body of the individual. However, in making the computation of the net heat load, one would certainly have to take into account the amount of clothing, the color of clothing, and the spectral distribution of the incident radiation.

A. I. Geyser, E. K. Geyser Company: Do you forecast the introduction of mechanical apparatus which will cyclicly vary humidity and temperature (around the desired norm)?

Mr. Logan: Yes, I do. Actually, it has been done sporadically. The first case I ran into was that of the Ford Motor Company when they built their Dearborn Laboratories in 1922. As a result of the types of studies I mentioned here, there was a temperature cycle introduced plus and minus 5° around 70° on a 30-minute basis. That installation operated with beneficial effect for many years, but it was way ahead of its time. I think we are now approaching the time when we can practically cycle our interior climate in the direction and to the degree that is most effective in maintaining the desired physiological tone of the occupants of the space.

Solar Effects on Architecture

By Vincent G. Kling, FAIA

Abstract: Sun effect, an important force affecting design concepts, must be considered by the architect in terms of orientation, geographical location, reflecting surfaces surrounding the design, and the basic concept of how the windows are handled. Sun control systems used by the architect include sun shading devices, glazing materials, interior devices, and control of the amount of glass in the building face. Examples of designs which recognize the sun effect, while respecting the environmental relationship and internal function, are given.

HISTORICALLY, THE INFLUENCE of sun on architectural design has been a very strong conditioning agent on the architect's pen. Much of the charm of the great Greek buildings is due to the use of massive stones with small openings which captured the sunlight in a very exciting manner. The deep shadows and modulating shade effects which resulted are as much a part of the design as the sculptured ornamentation. As the architect faces the problem today, he certainly must have equal respect for the sun effect on his buildings.

Before going into the specific design concerns of the architect, one other sun effect should be mentioned. That is the deleterious effect of the sun on the building materials and its long-term appearance. While we are considering the effect of the sun as the architect's paintbrush in bringing out the richness of his design, we must also consider it as the architect's enemy in destroying the appearance of this finished building as building materials succumb to the sun effect.

DESIGN CONSIDERATIONS

The architect concerns himself with the sun effects on building design mainly in terms of the following:

1. Orientation. Obviously if a building faces south, east, or west, direct sun will help to bring out richness of the texture. Orientation will also have some effect on the sizing of the

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glass which determines the architectural flavor of the building. There is no doubt that design of a building with a south-facing main entrance is much easier than design of a north-facing building. When a building faces into the sun, it can have much colder materials -- the colder granites, the blues and blue-grays, etc. If, however, the building has its main approach from the north, most architects feel that this requires the use of more vigorous forms and warmer materials.

2. Geographical location. Buildings on the Equator need a great deal of sun protection, while buildings in the northern countries can drink in much sunlight. The Scandinavians are using large amounts of glass because the sun is not with them long and their people are real sun-worshipers.
3. Reflecting surfaces surrounding the design. Large sweeps of white pavement which reflect light on the building can produce fascinating effects. Water can bring much sparkle to a building façade. Conversely, heavy dark-paved macadam surfaces which drink in a great deal of the sun's light also drink in a great deal of the heat which radiates against the building face. Surrounding buildings that are reflectors may constitute hazards in sending too much light into the building.
4. Basic concept of how the windows are handled. If the glass is out on the face of the building and becomes a mirror, then obviously a north-facing wall takes on the character of a series of mirrors set in a solid structure. The opposite is true of a south-facing building. Here the sun penetrates through the glass plane and strikes the interior surfaces of the building -- the walls, furniture, venetian blinds, or window shades. A south-facing building has a much easier time taking on a feeling of substance, solidity, and permanence than the north-facing building.

SUN CONTROL SYSTEM

There are a variety of solutions available to the architect, and they can all be used to vary the architectural flavor of a building:

1. Sun shading devices. Some buildings have shading devices on each floor which give even some vertical buildings a completely horizontal look. The shadow over the windows gives a banded effect that sets up a particular kind of architectural mood for the building. Setting the windows back from the face of the building provides a form of sun break as well as a strongly modulated façade.
2. Glazing materials. Shaded glass stops much of the glare and some of the heat but at the same time prevents views into the building. If use of shaded glass is not handled properly, the architect can produce a pretty deadly building. Tinted glass in various hues provides more subtle sun control, but

the color must be considered in the design and there are problems of reradiation effect.

3. Interior devices. Some in use today give quite interesting architectural effects. The translucent fabric blind is particularly noteworthy, because it gives a two-way effect which both the occupant and the man in the street can enjoy.
4. Control of the amount of glass in the building face. Without doubt, this is the most widely used system of sun control. We are being much more realistic about the use of glass. There are rare cases where marvelous views are to be had in the upper floors of buildings. However, some buildings in our urban environments begin to look ridiculous when the major part of their exterior facing is polished plate glass. The ultimate effect is that the occupants have to make them tenable by adding an absolute barrier of blinds and shades and draperies. The average south- or west-facing multiple story building with a large glass facing will appear completely deadly when all the blinds are pulled.

DESIGN EXAMPLES

The range of possibilities available to the architect in designing a building to recognize the sun effect, while still respecting the environmental relationship and the internal function, provides unlimited opportunity for individual expression. The following examples from my own practice illustrate this point.

The Transportation Center office building in Philadelphia is an east-west facing building -- the worst kind of orientation -- and therefore we used a very small window and a simple limestone facing. The average layman might feel that the Transportation Center has too few windows, but there is no shortage of natural light or views to the outside for the occupants within.

A new 30-story office building in Baltimore -- the Blaustein Building -- has a glass area limited by code to 35% of the wall area. Here we used a narrow, vertical, floor-to-ceiling window with deeply splayed jambs between to act as a sun break. By placing the windows out on the face of the building, the entire pane becomes a reflective surface, and the appearance is that of a building with much larger glass area. On the inside, the light and views are more than ample.

The new municipal office building in Norfolk, Virginia, although it has spaces facing east, south, and west (as well as north), overlooks the magnificent panorama of tidewater. We have taken maximum advantage of these wonderful views by providing all glass walls on every floor. To make it tenable for the occupants we have employed a "sun break" wall of two layers of glass, three feet apart. The inner layer is clear glass panes, nine feet tall from floor-to-ceiling, installed flush with the face of the building. The outer panes are heavily pigmented glass supported on lightweight tubular metal frames projecting off the columns on the building face. A horizontal louver sunshade at the head of each row of windows screens the direct rays of the sun and also serves as a walkway for window washers. The stack effect created between the two layers of glass permits air currents to rise freely and is calculated to carry off about 30% to 35% of the heat gain not absorbed in the air barrier. In terms of the air conditioning required to overcome the solar load, the result is the equivalent of a building with only 40% glass.

Whenever dark glass is used for glare control, a certain architectural flavor is achieved. The World Headquarters of Monsanto Chemical Company in St. Louis is an office building in which an automobile-type window glass -- composed of two sheets of glass with a pigmented vinyl membrane between -- was used for sun control. The glass is no longer transparent and one cannot see clearly into the central spaces of the building. Because of the effect this glass has on the substance and massing of the structure, we have used wall panels with a fairly high degree of gloss and a color that picks up somewhat the same spectrum as the pigment of the glass.

In summary, it is obvious that the esthetics of any building design come as much from a mature, realistic approach to the sun effect as from almost any other single force affecting design concepts. As the architect solves the problem of sun effect, he is putting his stamp and flavor on the architecture.

Solar Effects on Building Costs

By Elmer R. Queer and Everett R. McLaughlin, Pennsylvania State University

Abstract: Solar effects on overall costs of constructing, owning, and operating large commerical buildings are considered, using as an example a detailed present worth analysis of a large office building in New York City. Results of a special study of the economic influence of fenestration show that there is a long-term advantage of double over single glazing. Formulas are presented, using the values for heat absorbing double glazing in New York City, for 15 cost factors affected by solar radiation. Data are summarized in tabular form, and methods are given for analyzing structures in other geographical areas.

THIS PAPER DISCUSSES solar effects on the overall costs of constructing, owning, and operating large commercial and institutional buildings. The principles involved can be applied to smaller structures but may be unnecessarily detailed for homes and small manufacturing facilities.

To illustrate a procedure permitting consideration of all significant factors and their interrelationships, a large office building is analyzed in detail. Though the particular building is a tax-paying structure in New York City, methods and advice are given which make it practical to analyze other structures of different types in other geographical areas.

A special study has been made of the engineering and economic influence of fenestration on overall building costs and of its relationship to the comfort of occupants. Recommendations are included on how comfort conditions can be improved and on how overall costs can be reduced. Further avenues of research and development are suggested.

PRIMARY CONSIDERATIONS

It has long been the practice of the Building Owners and Managers Association to base cost analyses on the rentable square feet

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of available floor area. This is always less than the total area occupied by the building, a value of 80% being frequently experienced. One of the principal requirements of objective comparisons between buildings is the use of a standard procedure in determining rentable floor area. Though individual variations are encountered, the procedure set forth in American Standard Methods of Determining Areas in Office Buildings -- ASA Z65.1 (2) is widely used.

One of the most important considerations in building designs involving solar effects is the zoning arrangement. Direct solar effects apply primarily to the perimeter zone. This may extend toward the center of the building 15 to 30 feet, depending upon partition and duct arrangement. Because of direct exposure to solar radiation, the effects are greatest on the sunny elevations. Many design judgments and decisions must consider the influence of the design factors in each zone upon the other. Because this has not been completely studied in most structures, some designs have been less satisfactory than they might have been.

Recently a joint ASHRAE - IES Committee studied these relationships and prepared the summary which is shown in Table 1. Table 2 compares the figures for the office building (Table 1) with other recent installations.

Since large amounts of money are involved, both for capital investment and for operation, the allotment for each in a building budget should be carefully analyzed with all economic considerations in mind. Otherwise, judgment based on incomplete information may lead to difficulties for investors, owners, and operators of the building and possibly to less occupant comfort and satisfaction than might be achieved for the same expenditure. The principal factors which require consideration in a serious economic analysis are listed below:

1. Value of money
2. Inflation
3. Income tax
4. Real estate tax
5. Insurance
6. First costs
7. Salvage
8. Depreciation
9. Maintenance and operation
10. Support of wall
11. Space occupied by walls
12. Speed of construction
13. Air conditioning
14. Heat gain
15. Heat loss
16. Illumination
17. Solar radiation
18. Weather
19. Location and orientation.

The rented value of a given floor area is difficult to assess. Location, decor, and popularity have important economic influences.

RECOMMENDATIONS

The following recommendations are based upon experience and upon a special study of economic relationships between building components in which particular attention was paid to solar effects on overall costs.

TABLE 1 -- ACTUAL COOLING LOAD SOURCE DISTRIBUTION OF A MODERN OFFICE BUILDING[1]

Heat Source	Exterior Offices				Interior Offices
	North	East	South	West	
	(Percent at time of maximum load)				
Glass	27	56	51	56	---
Lights[2]	61	37	41	36	84
Occupants	12	7	8	8	16
	100	100	100	100	100

[1] Exterior masonry area was very small; heat gain through it was neglected.

[2] Heat from lighting was calculated at 5 watts per sq ft. It was assumed that occupants would lower venetian blinds on sunny side and turn on lights.

TABLE 2 -- COMPARISON OF TOTAL COOLING LOADS OF A MODERN OFFICE BUILDING AND OTHER RECENT INSTALLATIONS

Heat Source	Office Building A	Loan Office B	Chain Store C	Clinic D
	(Percent at time of maximum load)			
Glass	11.8	27.0[2]	5.7	14.8
Lights[1]	42.3	12.9	23.3	16.9[3]
Roof & walls	00.7	16.8	12.0	33.4
Occupants	15.4	12.2	33.4	15.5
Ventilation	26.6	31.1	21.4	19.4
System power	3.2	----	4.2	----
	100.0	100.0	100.0	100.0
Glass plus lights	54.1	39.9	29.0	31.7

[1] Heat from lighting in Column A was calculated at 5 watts per sq ft, in Columns B and C at 3 watts per sq ft, and in Column D at 2.5 watts per sq ft.

[2] Large expanse of window exposed west.

[3] Assumes 50% of lights in use.

1. Average figures for locations throughout the United States show that the ultimate cost of owning insulating glass per square foot of rentable floor area is the lowest of the transparent fenestrations studied.
2. First cost of the glass has a direct effect on ultimate cost of owning the rentable floor area. For a building with the proportions used in this study, each dollar change in the first cost of a square foot of glass results in a 30-cent change in the ultimate cost of owning a rentable square foot of floor for 50 years.
3. The present study does not include any value for vision and appearance. Present cost evaluations do not recognize that vision and beauty have real monetary value. It may be feasible to develop a relationship which will permit the addition of vision and beauty values into the cost of owning.
4. There is no mechanism to express a dollar value for the comfort of glasses and panels. It may be necessary to assign arbitrary values to include comfort in the ultimate cost.
5. Consumers and architects need guidance on how to use glass, and the mechanical designer needs assistance in providing maximum comfort with reasonable utilization of fuel energy. It has been customary to base calculations for the amortization or cost of owning fenestration on the winter heating costs. It is important to consider the savings in capital equipment for both heating and air conditioning as well as the savings in heating and air conditioning operating costs. Good practice recommendations on glass applications which increase comfort and reduce building costs attributable to large glass areas should be developed, correlated, and published.
6. Improved performance would have a definite effect on the ultimate cost of owning for 50 years. If the U value of the heat-absorbing insulating glass were improved from 0.55 to 0.40 Btu/ft^2/hr/°F (which is a major reduction), the heat loss charge would be reduced 25%. This represents 0.4% reduction in the ultimate cost. Similarly, a reduction of 25% in the heat gain factor (34.7 to 26.0 Btu/ft^2/hr) would reduce the ultimate cost of owning 0.7%.
7. Maintenance of fenestration can be improved by easier and faster cleaning methods, special equipment, and dirt-repelling surfaces.
8. Automatic illumination controls offer considerable promise through reduced costs for cooling equipment and operation. The high solar load coincides with the high natural illumination. Reducing the artificial illumination during these periods results in several benefits. The cooling capacity required to remove the heat generated by the lights is reduced. The energy cost for artificial lighting is reduced. The lighting equipment has a longer life with less frequent replacement. The success of such a control depends on a combination of sim-

plicity and reliability, with a modulating action which is not distracting. On-off control of the entire lighting system or a major part thereof is not likely to be popular. Studies with control systems indicate that substantial potential savings are practically attainable.

DISCUSSION OF RESULTS

The study revealed a long-term advantage of double over single glazing. However, the economic importance of glass cleaning costs and the potential value of automatic electric lighting controls[1] which the study revealed were completely unexpected. These data were developed by studying a $3 million ten-story, 100 by 100 ft office building located in New York City. Walls were faced north, south, east, and west on an unshaded site. The procedure used for the analysis was based on the present worth concept (3, 4) which is widely recognized by accountants as more accurate than amortization formulas.

Many arbitrary assumptions were necessary in setting up the study conditions. However, checks against published data on actual buildings indicate that the results are of the right order of magnitude.

The calculations are fully detailed. Changes in the basic assumptions will, of course, influence the results. However, checks have indicated that likely variations will not change the results enough to warrant drawing up different recommendations, when the ratio of glass area to total wall area is greater than 25% and the useful life of the building is more than 30 years. Specific instructions are provided, if it is desired to study other building types or job conditions. (See section on Computations and Analysis.)

Taxes affect the ultimate cost of owning a wall in several ways. There is a tendency to accept materials having a lower first cost and higher maintenance costs, since operating expenditures may be deducted for income purposes. This is offset by the allowances for depreciation, which would be higher for a higher first cost. On the other hand, it is enhanced by the interest which could accrue on the difference in first cost if it were invested.

There are at least two tax categories for ownership: taxable and tax-free. The latter category includes public buildings, schools, churches, and non-profit institutions. Any tax rate used must be a composite figure for federal, state, and local income taxes over the anticipated life of the building.

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[1] The automatic electric lighting control is a device developed to control the electric illumination in an inverse ratio to the available natural illumination. It is accomplished by a photoelectrical control that cuts out sections of the electric lighting as the solar illumination increases and turns them on as natural light decreases.

Real estate taxes are quite variable in tax rates and in computation of the ratio of assessed value to market value. Some attempt has been made to reflect these differences for geographic areas.

Insurance is a factor which varies considerably with the policy of the rating bureau and the material of construction. Coverage is not required for the total initial cost, as part of the initial cost is for items not readily destroyed by fire. The cost for insurance is a small part of the ultimate cost of owning a wall.

Cities with representative balance between summer and winter conditions were selected for study (1, 5).

ORIENTATION

The orientation of a building affects the solar radiation which strikes a given wall and, depending on the construction of the wall, affects the cooling equipment required. In the North Temperate Zone the wall facing south will receive more energy throughout the day than the wall facing north. Other orientations may have even greater loads, as the factors of radiation rates and angles of incidence combine to produce high loads.

Maximum solar radiation rates are plotted for each orientation in Fig. 1. For this analysis the average of the loads for the four principal compass points has been used.

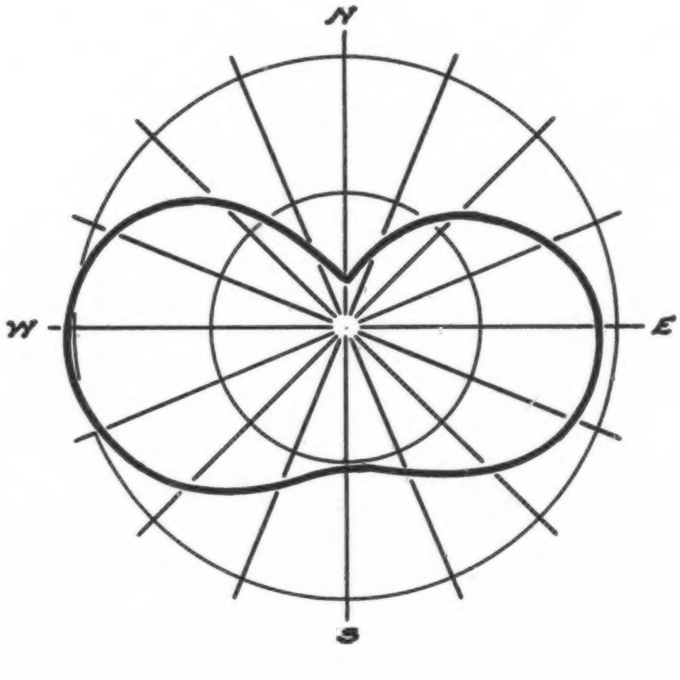

Figure 1 -- Maximum cooling loads vs. orientation, 40° North Latitude, 1/4 in. plate glass.

COMPUTATIONS AND ANALYSIS

To calculate the ultimate cost on the basis of rentable floor area, it is necessary to include the cost of the building structure and its maintenance over the life of the building. For this purpose a 100 ft by 100 ft building having 48,000 sq ft of wall area covering ten stories was selected as a model. It is assumed that 80% of the total floor area is rentable, making a total of 80,000 sq ft, and that the building will be located in New York City.

The results of these calculations are given in Table 3. The table follows the basic practice in cost considerations in relating the cost of the building to rentable floor area. The first costs are seen to range from about $32 to $35 per sq ft of rentable floor area. Present worth of ultimate costs based on an anticipated 50-year life of the building range from about $50 to $55 per sq ft of rentable floor area, depending upon the make-up of the wall. Also included is the uniform annual cost which ranges from about $3.23 to $3.46 per sq ft

TABLE 3 -- OWNERS' TOTAL COSTS PER SQUARE FOOT OF RENTABLE FLOOR AREA[1]

Wall	Glass Type	First Cost[2]	Present Worth of Ultimate Costs[3]	Uniform Annual Costs[4]
50% glass/ 50% masonry	1 in. double window with solar retardant	$33.78	$52.71	$3.34
	1 in. double window	33.31	52.52	3.33
	1/4 in. solar retardant	32.55	52.78	3.35
	1/4 in. plate glass	32.38	52.79	3.35
	7/32 in. sheet glass	32.21	52.63	3.34
50% glass/ 50% panel	1 in. double window with solar retardant	34.66	53.43	3.39
	1 in. double window	34.19	53.34	3.38
	1/4 in. solar retardant	33.43	53.50	3.39
	1/4 in. plate glass	33.26	53.51	3.39
	7/32 in. sheet glass	33.09	53.35	3.38
100% glass	1 in. double window with solar retardant	35.30	54.44	3.45
	1 in. double window	34.36	54.06	3.43
	1/4 in. solar retardant	32.84	54.58	3.46
	1/4 in. plate glass	32.50	54.60	3.46
	7/32 in. sheet glass	32.16	54.28	3.44
100% masonry		32.26	50.98	3.23
100% metal panel		34.02	51.70	3.28

[1] New York City.

[2] Includes architects' fees and land.

[3] Includes first cost but excludes land.

[4] Present Worth x Capital Recovery Factor, excludes land.

of rentable floor area, a variation of about $0.23. In determining these total costs, the individual items were found to exert proportional influences similar to those shown in Table 4.

Certain assumptions must be made on economic factors, such as interest or cost of borrowing money, energy costs, inflation, and taxes. Where the same assumptions are made for the costs of walls being compared, the comparison will be valid. Past trends should be evaluated over a sufficiently long interval to permit projection into the future.

TABLE 4 -- DISTRIBUTION OF COSTS
FOR BUILDING WITH 50% DOUBLE WINDOWS
WITH SOLAR RETARDANT

Item	New York City First Cost	Ultimate 50-Year Cost
	(%)	(%)
Glass and glazing	5	4
Sash	2	1
Glass		
Heating	1	2
Cooling	4	3
Cleaning	-	2
Masonry	2	6
Other heating	1	1
Other cooling	2	1
Electrical	10	7
Land	22	0
Architects' fees	5	3
Maintenance and operation		20
Insurance		1
Real estate tax		23
Structure and accessories	46	26
Total	100	100

FACTORS AFFECTED BY SOLAR RADIATION

First costs are not immune from certain solar effects, as they are influenced by the weather and by shipping charges. Weather conditions during construction also influence erection costs.

Table 5 shows basic cost factors common to all wall panels.

TABLE 5 -- BASIC COST FACTORS COMMON TO ALL WALL PANELS

Factor	Base
Value of money	6% per annum or 0.00115 per week
Anticipated useful life of building	50 years
Depreciation rate on buildings	2% per year
Anticipated useful life of mechanical equipment	20 years
Depreciation rate on mechanical equipment	5% per year
Anticipated average annual rate of price changes	
Income taxes	none
Real estate taxes	+0.02
Insurance	+0.01
Mechanical equipment	+0.0377
Combined heating plant maintenance and fuel	+0.0333
Combined air conditioning plant maintenance and electricity	+0.02
Maintenance on walls	+0.0377
Electricity	+0.01
Total equivalent income tax rate	57% of profit
Real estate taxes	
Ratio of assessed value to market value	0.75
Tax rate	4% per $100 assessed valuation (See Table 7)
Concrete costs	
Superstructure	$80.00 per cu yd
Foundations	$35.00 per cu yd
Air conditioning	
Initial plant cost	$ 0.13 per Btu hourly capacity
Power costs	$ 0.02 per kw-hr
Power input per ton	1.6 kw
Wall orientation	Average of N, E, S, and W
Design temperature	(See Table 7)
Summer degree days per year	(See Table 7)
Heating	
Initial plant cost	$ 0.02 per Btu of hourly capacity
Fuel cost	$ 0.17 per therm (100,000 Btu)
Design temperature	(See Table 7)
Heating degree days per year	(See Table 7)
Illumination	
Power cost	$ 0.02 per kw-hr
Lamp replacement cost	$ 0.04 per watt
Design level	75 foot-candles
Illumination (foot-candles per watt per sq ft of floor area)	15 foot-candles
Normal lamp life	8000 hr

Calculations in this study of the specific cost factors for each wall panel were made in accordance with the formulas presented here. Examples are based on values for heat absorbing double glazing in New York City.

1. First cost.

Costs of wall materials and their erection are based on typical information from reliable sources. The use of a median has been attempted to avoid values which are misleading because of non-typical features in the construction. The choice of a typical first cost is important because this affects the ultimate cost almost directly. Values of the initial cost of walls selected for this analysis are shown in Table 6.

Example: $7.66 for heat absorbing double glazing, installed, including sash.

2. Support of the wall charge.

With a wide variation in the weight per square foot of wall, it has been assumed that a portion of the cost of erecting the structural frame and foundations should be considered a part of the initial cost. The mathematical expression for this charge is:

$$Ch = \frac{P(16.63 + F)}{6670}$$

Where: C_h is the initial construction cost of the structural frame and foundations attributable to one square foot of wall area.

P is the weight of the wall in pounds per square foot.

F is the number of floors.

Example: $C_h = \frac{7(16.33 + 10)}{6670} = \$0.03$

3. Charge for floor space occupancy.

When space is limited, and this is assumed to be the case only if the building walls are erected on the building restriction line, the thickness of the wall is an economic factor. The walls occupy rentable or usable floor space, and the cost of providing this space is calculated by the following formula:

$$C_{fw} = \frac{C_f Y}{12S}$$

Where: C_{fw} is the initial cost per square foot of wall area for providing the additional floor space occupied by the wall.

C_f is the cost of the building per square foot of floor area.

TABLE 6--COST FACTORS PERTINENT TO EACH WALL PANEL, WITH TYPICAL SUMMARY FOR NEW YORK CITY

Wall Type	Masonry Wall	Panel Wall	1/4 inch Plate Glass	Heat Absorbing Glass	Heat Absorbing Double Glass	Double Glass
1. Thickness	10 in.	6 in.	2.5 in.	2.5 in.	3 in.	3 in.
2. Height	12 ft	12 ft	12 ft	12 ft	12 ft	12 ft
3. Weight	65 lb/ft^2	16 lb/ft^2	4 lb/ft^2	4 lb/ft^2	7 lb/ft^2	7 lb/ft^2
4. U value (Btu/ft^2/hr/F)	0.12	0.12	1.13	1.13	0.55	0.55
5. Color	med	med	-	-	-	-
6. Interior artificial illumination	2000 hr/yr	2000 hr/yr	500 hr/yr	500 hr/yr	500 hr/yr	500 hr/yr
7. Initial cost	\$2.60[1]	\$5.54	\$2.99	\$3.58	\$7.66	\$6.09
8. Salvage value	\$0.16	\$0.80	\$0.25	\$0.32	\$0.77	\$0.77
9. Maintenance costs & frequency						
Exterior	\$0.07/35 yr	\$0.02/8 yr	\$0.01/mo	\$0.01/mo	\$0.01/mo	\$0.01/mo
Interior	-	-	0.01/mo	0.01/mo	0.01/mo	0.01/mo
Cleaning blinds	-	-	0.05/yr	0.05/yr	0.05/yr	0.05/yr
Pointing	\$0.50/35 yr	-	-	-	-	-
Calking	-	\$0.08/8 yr	\$0.06	\$0.06	\$0.06	\$0.06/16 yr
Painting interior	\$0.05/3 yr	\$0.05/3 yr	-	-	-	-
10. Fire insurance (dollars/\$100 value)						
Building	\$0.06	\$0.08	\$0.08	\$0.08	\$0.08	\$0.08
Contents	\$0.18	\$0.20	\$0.20	\$0.20	\$0.20	\$0.20
11. Heat flow rate (Btu/ft^2/hr)	1.23	2.55	45.9	41.4	34.7	41.5

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[1] Minimum cost masonry wall

Y is the wall thickness in inches.

S is the floor wall height in feet.

Example: $C_{fw} = \frac{19.95 \times 3}{12 \times 12} = \$0.41$

4. Total initial wall cost.
   This total cost is the sum of Items 1, 2 and 3.

   Example: \$7.66 + \$0.03 + \$0.41 = \$8.10

5. Depreciation credit.
   There are many methods for computing the depreciation of exterior walls. In certain instances very rapid depreciation is used or permitted. For this analysis, depreciation is assumed on a straight line basis over the 50-year life of the building.

$$V_{pd} = F_u \, T C_t \, D_b$$

Where: V_{pd} is the present value of the initial cost recovered by depreciation tax credit per square foot of wall area.

F_u is the present worth factor for a uniform annual series for the tax life of the building.

$$F_u = \frac{(1 + i)^N - 1}{i \, (1 + i)^N}$$

i is the interest rate.
N is the number of time periods.

Note: i and N must be functions of the same period of time. If i is the interest rate per annum, N is expressed in years.

T is the total equivalent income tax.

C_t is the total initial cost attributable to the wall per square foot, including wall construction, cost of supporting the wall, and a charge for floor space occupancy, if any.

D_b is the annual depreciation rate.

Example: $V_{pd} = 15.762 \times 0.57 \times 8.10 \times 0.02 = \$1.46$

6. Salvage credit.

The present scrap value of the wall must be converted to the present value of the anticipated salvage income less taxes at the end of the 50-year life of the building.

$$V_{ps} = F_s\, C_s\, (1 + Nf)\, (1 - T)$$

Where: F_s is the present worth factor for a single future payment.

or $\frac{1}{(1 + i)^N}$ i is the interest rate. N is the number of time periods.

C_s is the present scrap value.

N is the time in years.

f is the average annual rate of price change.

T is total equivalent income tax rate.

Example: $V_{ps} = 0.0543 \times 0.77\ (1 + 50 \times 0.0377)\ (1 - 0.57)$
$= \$0.05$

7. Early occupancy credit.

Where speed of erection is a factor in permitting earlier occupancy and providing a quicker return on the investment, the present value of the savings per square foot of wall area may be calculated:

$$V_{po} = \frac{C_b}{A_g}\left[1 - \frac{1}{(1 + i)}\, W\right]$$

Where: V_{po} is the present value of the savings per square foot of wall area made by a faster return on the investment due to earlier occupancy.

C_b is the investment or total initial cost of the building.

A_g is the gross exterior wall area in square feet.

i is the rate of return on the investment.

W is the number of time periods saved by earlier occupancy (1.9 weeks).

Example: $$V_{po} = \frac{3.00 \times 10^6}{48{,}000}\left[1 - \frac{1}{(1 + 0.00115)}1.9\right]$$

$$V_{po} = \$0.14$$

8. Air conditioning credit for daylight illumination.

Use of daylight illumination when solar radiation is prevalent permits a reduction in use of electrical illumination. This results not only in a reduction of the electrical energy consumption and reduced lamp replacement costs but, with proper control, also permits a reduction in the air conditioning capacity. The control prevents the lighting load and the solar load from occurring at the same time. On overcast days, when electrical illumination is required, the air conditioning load from the glass areas is much reduced, consisting of a transfer of diffuse radiation. The first of these loads can be calculated by multiplying the difference between interior and exterior design temperatures by the transmittance value, U.

$$H_{gc} = (t_o - t_i)\,U$$
$$= (85 - 76) \times 0.55 = 4.95 \text{ Btu/ft}^2\text{/hr}$$

The diffuse radiation transfer has been estimated at 5.00 Btu/ft^2/hr. The total heat load is 10.0 Btu/ft^2/hr. The heat load from the electrical illumination is calculated on a basis of 5 watts per square foot of floor area and 2.5 sq ft of floor area per sq ft of window area. This equivalent 12.5 watts per sq ft of window area represents 42.7 Btu/ft^2/hr. When the electrical illumination is reduced, the net reduction of air conditioning capacity is:

$$H_{ac} = H_i - H_{gc} - H_{gd}$$

Where: H_i is the heat load from electrical illumination.

H_{gc} is the heat load from temperature difference across the window.

H_{gd} is the heat load from diffuse radiation.

Example: $H_{ac} = 42.7 - 4.95 - 5.00$

$= 32.7$ Btu/ft^2/hr

The credit to be allowed for the glass is calculated by the same formula used for the heat gain charge in Item 8 above. This accounts for savings in first cost of the air conditioning equipment, rebuilding every 20 years, depreciation, insurance, real estate tax, and operating costs. By proportionality the credit is:

$$V_{pac} = \frac{H_{ac}}{H_g} \times v_{pg}$$

Where: V_{pac} is the present value of the reduction in the air conditioning plant capacity and operating costs to be credited to the window.

H_{ac} is the net reduction in the air conditioning plant capacity.

H_g is the heat gain through the window from solar radiation as used in Item 10.

V_{pg} is the present value of the summer air conditioning plant first cost and operating costs as calculated in Item 10.

Example: $V_{pac} = \frac{32.7}{34.7} \times 4.97 = \$4.69$

9. Illumination charge.

Windows permit the use of natural illumination to supplement artificial illumination. The cost of electric power and lamp replacement can be expressed in present values by the formula:

$$V_{pi} = \frac{IQ\ (1 - T)}{W} \left[\frac{E\ (L)\ F_u P_u + C_l\ (F'_{nu})}{1000} \right]$$

Where:	I	is the illumination design level at the working plane in foot-candles.
	Q	is the average ratio of floor area in rooms with windows to window area.
	W	is the illumination provided in foot candles per watt of electricity per square foot of floor area.
	T	is the total equivalent income tax rate.
	E	is the electric power costs per kw-hr.
	L	is the annual number of hours of artificial illumination.
	F_u	is the present worth factor for a uniform annual series of equal future expenditures during the life of the building.
	P_u	P_u the approximate present worth correction factor for a uniformly increasing series of future annual expenditures. ($P_u = 1.175$)
	C_l	is the lamp replacement cost per watt.
	F'_{nu}	is the present worth factor for a non-annual series of uniformly increasing cost to replace lamps.

Example:

$$V_{pi} = \frac{75 \times 2.5 \times 0.43}{15} \left[\frac{0.02 \times 800 \times 15.762 \times 1.175}{1000} + 0.04 \times 2.124 \right]$$

$$= \$2.06$$

10. Heat gain charge.

Heat penetrating a building wall into the air conditioned space can be removed at considerable expense. Total annual cooling costs per Btu of hourly plant capacity, X_g, were estimated as the annual power cost for cooling per Btu of heat gain plus 50% for operating personnel and maintenance. The combination of summer degree days and the corresponding winter degree days was plotted and cities were selected for study as representative of conditions to be encountered in the

United States. The west coast cities have very few summer degree days but have a range of winter degree days. See Table 7, page 58.

$$X_g = 1.5\ C_g = \frac{1.5\ KEG}{(t_d - 1.5t_r - 70)\ 500}$$

Where: X_g is total annual cooling cost per Btu of hourly plant capacity.

C_g is annual electric power cost per Btu of hourly plant capacity.

K is the number of summer degree days.

E is the electric power cost per kw-hr

G is the power input in kw per ton.

t_d is the design exterior temperature.

t_r is the diurnal temperature range.

Example: $$X_g = \frac{1.5 \times 250 \times 0.02 \times 1.6}{(95 - 0.5 \times 20 - 70) \times 500}$$

$$= 0.0016$$

The initial and present value of future operating costs of a summer air conditioning plant necessary to meet the heat gain through the wall must be added to the initial wall cost. These values may be calculated as follows:

$$V_{pg} = H_g M_g \left[1 + F'_{nu} (1 - T) - D_g T F'_u + I_r F_u (1 - T) + V_t R_t F_u (1 - T) \right] + X_g H_g P_u F_u (1 - T)$$

Where: V_{pg} is the present value of the initial cost and operating cost of the air conditioning plant attributed to 1 sq ft of wall area.

H_g is the heat gain through the wall in Btu per hour per square foot.

M_g is the initial cost of the air conditioning plant per Btu of hourly capacity.

TABLE 7 -- SUMMER HEAT GAIN DATA

Geographical Location	Latitude Used	Average Temp., Summer	Summer Degree Days	Masonry	Metal Panel Wall	1/4 inch Plate Glass	Solar Retardant	Double Window with Solar Retardant Outside	Double Window
				(Heat gain in Btu/ft^2/hr)					
Phoenix	30°	97°	2200	1.16	2.41	44.0	38.6	32.8	40.6
Los Angeles	30°	81°	0	1.16	2.41	44.0	38.6	32.8	40.6
Shreveport	30°	88°	1500	1.16	2.41	44.0	38.6	32.8	40.6
Little Rock	40°	90°	1000	1.23	2.55	45.9	41.4	34.7	43.5
San Francisco	40°	79°	0	1.23	2.55	45.9	41.4	34.7	43.5
Richmond	40°	87°	740	1.23	2.55	45.9	41.4	34.7	43.5
Portland	40°	81°	0	1.23	2.55	45.9	41.4	34.7	43.5
Kansas City	40°	94°	500	1.23	2.55	45.9	41.4	34.7	43.5
New York	40°	85°	250	1.23	2.55	45.9	41.4	34.7	43.5
Denver	40°	85°	100	1.23	2.55	45.9	41.4	34.7	43.5
Buffalo	40°	80°	0	1.23	2.55	45.9	41.4	34.7	43.5
Minneapolis	40°	86°	0	1.23	2.55	45.9	41.4	34.7	43.5
Bismarck	50°	86°	0	1.32	2.73	49.2	44.3	37.0	46.4
Duluth	50°	84°	0	1.32	2.73	49.2	44.3	37.0	46.4

F'_{nu}	is the present worth factor for a non-annual series of expenditures to rebuild the air conditioning plant when rebuilding cost is expected to change.
T	is the total equivalent income tax rate.
D_g	is the depreciation rate on the air conditioning plant.
F'_u	is the present worth factor for a uniform annual series of depreciation tax credits on the air conditioning plant, when rebuilding costs are expected to change.
I_r	is the insurance rate on the building with the wall type under consideration.
F_u	is the present worth factor for a uniform annual series to the life of the building = 15.762.
V_t	is the ratio of tax assessed value to market value of the air conditioning plant.
R_t	is the real estate tax rate.
X_g	is the total annual cooling costs per Btu of hourly plant capacity.
P_u	is the approximate present value correction factor for a uniformly changing series of future annual expenditures = 1.32.

Example:

$$\begin{aligned} V_{pg} &= 34.7 \times 0.13 \\ &\Big[1 + 0.791\ (1 - 0.57) \\ &- 0.05 \times 0.57 \times 19.54 \\ &+ 0.0006 \times 15.762\ (1 - 0.57) \\ &+ 0.75 \times 0.04 \times 15.762 \times (1 - 0.57)\Big] \\ &+ 0.0016 \times 34.7 \times 1.32 \times 15.762\ (1 - 0.57) \\ &= \$4.97 \end{aligned}$$

11. Heat loss charge.

Annual operating costs per square foot of wall area, X_h, are computed by the following formula:

$$X_h = \frac{D_d\, C_h}{(t_i - T_o)\, 4167}$$

Where:

X_h	is the annual operating cost per Btu of hourly capacity.
D_d	is the heating degree-days per year.
C_h	is the operating cost of the heating plant per therm (100,000 Btu) of hourly capacity.
t_i	is the inside design temperature.
t_o	is the outside design temperature.

The relationship of winter design temperature to winter degree days was plotted for the cities selected for study. See Table 8.

Example: $$X_h = \frac{5000 \times 1.5 \times 0.17}{(70 - 0)\, 4167} = 0.00437$$

TABLE 8 -- WINTER HEAT LOSS DATA

Geographical Location	Latitude	Winter Degree Days	Design Temp., Winter
Phoenix	30°	1500	35°
Los Angeles	30°	1500	40°
Shreveport	30°	2000	14°
Little Rock	40°	3000	10°
San Francisco	40°	3000	40°
Richmond	40°	4000	10°
Portland	40°	4000	10°
Kansas City	40°	5000	-10°
New York	40°	5000	0°
Denver	40°	6000	-10°
Buffalo	40°	7000	-5°
Minneapolis	40°	8000	-25°
Bismarck	50°	9000	-30°
Duluth	50°	9600	-30°

The initial cost and the present value of operating costs of the heating plant required by each square foot of wall area, including real estate taxes, insurance, and rebuilding costs less depreciation on the plant, are calculated by the following formula:

$$\begin{aligned} V_{ph} = M_h U (t_i - t_o) \Big[& 1 + F'_{nu} (1 - T) \\ & - TD_h F'_u \\ & + V_t R_t F_u (1 - T) \\ & + I_r F_u (1 - T) \Big] \\ & + U (t_i - t_o) X_h (1 - T) P_u F_u \end{aligned}$$

Where:	V_{ph}	is the present value of the annual heating cost and the initial cost of the heating plant attributed to each square foot of wall area.
	M_h	is the initial cost of heating plant per Btu of hourly capacity.
	U	is the heat loss through 1 sq ft of wall area in Btu per hr per °F differential across the wall.
	t_i	is the inside design temperature, °F.
	t_o	is the outside design temperature, °F.
	F'_{nu}	is the present worth factor for a non-annual series of expenditure to rebuild the heating plant when rebuilding cost is expected to change = 0.791.
	T	is the total equivalent income tax rate.
	D_h	is the depreciation rate on the heating plant.
	F'_u	is the present worth factor for a uniform annual series of tax credits on the heating plant, when rebuilding costs are expected to change = 19.54.
	V_t	is the ratio of tax assessed value to market value of the heating plant.

R_t is the real estate tax rate.

F_u is the present value factor for a uniform annual series for the life of the building = 15.762.

I_r is the insurance rate on the building with the wall under consideration.

X_h is the total annual heating costs per Btu of hourly plant capacity.

P_u is the approximate present worth correction factor for a uniformly changing series of future annual expenditures = 1.53.

Example:
$$\begin{aligned} V_{ph} &= 0.02 \times 0.55 \times (70-0) \\ &\quad \Big[1 + 0.791 \times 0.43 \\ &\quad - 0.57 \times 0.05 \times 19.54 \\ &\quad + 0.75 \times 0.04 \times 15.762 \times 0.43 \\ &\quad + 0.0006 \times 15.762 \times 0.43\Big] \\ &\quad + 0.55 \times (70-0) \times 0.00437 \times 0.43 \times 1.53 \\ &\quad \times 15.762 \\ &= \$2.51 \end{aligned}$$

12. Maintenance charge.

The maintenance schedule for the window is:

$0.12 per year cleaning inside.
$0.12 per year cleaning outside.
$0.05 per year cleaning blinds.
Total $0.29 per year.

The present value of making an expenditure every year for the next 50 years is:

$$V_{pm'} = F_u \, P_u \, C\,(1-T)$$

Where: V_{pm} is the present value of making an expenditure every year for the next 50 years.

F_u is the present worth factor for a uniform annual series for the tax life of the building = 15.762.

P_u is the approximate present worth correction factor for a uniformly increasing series of future annual expenditures = 1.59.

C is the yearly cleaning cost.

T is the total equivalent income tax rate.

Example: $V_{pm} = 15.762 \times 1.59 \times 0.29\ (1-0.57)$

$= \$3.13$

Windows will require an expenditure of $0.06 per sq ft for calking every 16 years. The present worth of this cost is calculated as:

$$V_{pm16} = F'_{nu16}\ C(1-T)$$

Where: F'_{nu16} is the present worth factor for a 16-year series of calking costs.

C is the cost for calking.

T is the total equivalent income tax rate.

Example: $V_{pm16} = 1.145 \times 0.06 \times (1-0.57)$

$= \$0.03$

The total maintenance charge is the sum of cleaning and calking costs:

$$V_{pm} = V_{pm'} + V_{pm16}$$

$$= 3.13 + 0.03 = \$3.16$$

13. Insurance charge.

The present value of the fire insurance costs on a building chargeable to the wall may be computed as follows:

$$V_{pf} = C_u\ I_r\ P_u\ F_u\ (1-T)\ E$$

Where: V_{pf} is the present value of the fire insurance costs attributable to 1 sq ft of wall area.

C_w is the value of the wall under consideration.

I_r is the insurance rate on the building with the wall under consideration.

P_u is the approximate present worth correction factor for a uniformly changing series of future annual expenditures = 1.45.

F_u is the present worth factor for a uniform annual series for the life of the building = 15.762.

T is the total equivalent income tax rate.

E is the ratio of the initial replacement cost to initial building cost.

Example: $V_{pf} = 8.10 \times 0.0008 \times 1.45 \times 15.762 \times 0.43 \times 0.94$

$= \$0.06$

14. Real estate tax charge.

The present value of a future real estate tax chargeable to 1 sq ft of wall area may be computed as follows:

$$V_{prt} = C_t R_t V_t F_u (1 - T)$$

Where: C_t is the total initial cost of the wall per square foot.

R_t is the local real estate tax rate per year.

V_t is the local ratio of assessed valuation to market value.

F_u is the present worth factor of a uniform annual series for the life of the building.

Example: $V_{prt} = 8.10 \times 0.04 \times 0.75 \times 15.762 \times 0.43$

$= \$1.65$

Values used in this analysis are found in Table 9.

15. Ultimate cost, 50 years.

The 50-year ultimate cost is the sum of Items 4, 9, 10, 11, 12, 13, and 14 less the sum of Items 5, 6, 7, and 8.

Example: $\$8.10 + 2.06 + 4.97 + 2.51 + 3.16 + 0.06 + 1.65 - (1.46 + 0.05 + 0.14 + 4.69) = \$16.17$

TABLE 9--REAL ESTATE TAX DATA

Geographical Location	Tax Rate	Ratio of Assessed Valuation to Market Value
	(Percent)	
Phoenix	4*	0.50*
Los Angeles	10	0.35
Shreveport	3*	0.25*
Little Rock	4*	0.50*
San Francisco	4*	0.75*
Richmond	2	1.00
Portland	7	0.50
Kansas City	6*	0.40*
New York	4	0.75
Denver	5	0.40
Buffalo	4	0.60
Minneapolis	15	0.17
Bismarck	7	0.25
Duluth	7*	0.25*

*Estimated value.

The costs for each of the factors considered for each wall panel are summarized in Table 10.

The ultimate cost of owning the wall (Table 10) is combined with the other ultimate costs of owning the structure (Table 11) to obtain the ultimate cost of owning a square foot of rentable floor area. The owner's total costs of owning the square foot of rentable area are summarized in Table 3 (page 47).

INTEREST AND TIME

For those who wish to study the effect of interest rates or depreciation rates, the formulas can be utilized with factors for the proper rate. The interest rate will affect the present worth factors for single future payments (F_s), and uniform series of future annual payments (F_u) in accordance with the following equations:

$$F_s = \frac{1}{(1 + i)^N}$$

$$F_u = \frac{(1 + i)^N - 1}{i\,(1 + i)^N}$$

TABLE 10--TYPICAL COSTS FOR 7 PANELS, NEW YORK CITY

Cost Item	Masonry	Metal Panel	1/4 inch Plate Glass	Solar Retardant	Double Window	Double Window with Solar Retardant Outside	7/32 in. Sheet Glass
1. First cost							
a. Cost of glass or panel		$3.44	$1.03	$1.62	$3.50	$5.07	$0.48
b. Cost of installation of glass or panel		0.50	0.88	0.88	1.00	1.00	0.88
c. Cost of sash or frame		0.90	0.58	0.58	0.89	0.89	0.58
d. Cost of installation of sash or frame		0.70	0.50	0.50	0.70	0.70	0.50
e. Total first cost of wall, Cw	$2.60[1]	5.54	2.99	3.58	6.09	7.66	2.44
2. Support of the wall charge, Ch	0.26	0.06	0.03	0.03	0.03	0.03	0.03
3. Charge for floor space occupancy, Cfw	1.25	0.81	0.33	0.33	0.41	0.41	0.33
4. Total initial wall cost, Ct	4.11	6.41	3.35	3.94	6.53	8.10	2.80
5. Less depreciation credit, Vpd	0.74	1.15	0.60	0.71	1.17	1.46	0.50
6. Less salvage credit, Vps	0.01	0.05	0.02	0.02	0.05	0.05	0.02
7. Less early occupancy credit, Vpo	-	0.14	0.14	0.14	0.14	0.14	0.14
8. Less air conditioning credit (Illumination)	-	-	3.79	3.79	4.69	4.69	3.79
9. Illumination charge	5.22	5.22	2.06	2.06	2.06	2.06	2.06
10. Heat gain charge, Vpg	0.18	0.37	6.57	5.93	5.94	4.97	6.57
11. Heat loss charge, Vph	0.55	0.55	5.16	5.16	2.51	2.51	5.16
12. Maintenance charge, Vpm	0.24	0.26	3.16	3.16	3.16	3.16	3.16
13. Insurance charge, Vpf	0.03	0.05	0.03	0.03	0.05	0.06	0.02
14. Real estate tax charge, Vprf	0.83	1.20	0.68	0.80	1.33	1.65	0.57
15. Ultimate Cost, 50-year	10.40	12.81	16.45	16.42	15.53	16.17	15.89
16. Relative Ultimate Cost	0.67	0.83	1.06	1.06	1.00	1.04	1.02

[1] Minimum cost for masonry

TABLE 11 -- PRESENT VALUE OF OWNER'S ULTIMATE 50-YEAR COST FOR RENTABLE FLOOR AREA

Cost Item		Value
Initial cost of building structure		$1,720,000.00
Less salvage credit		5,810.00
	Sub Total, 1	$1,714,190.00
Less depreciation credit		309,000.00
	Sub Total, 2	$1,405.190.00
Maintenance and operation		932,000.00
Insurance		12,675.00
Real estate tax		1,093,000.00
Ultimate 50-year cost of owning building structure (less walls)		$3,442,865.00
Ultimate 50-year cost of owning rentable floor area (structure only)		$43.09 per sq ft
Ultimate 50-year cost of owning heat absorbing double window 24,000 sq ft x $16.17/80,000 sq ft		4.85 per sq ft
Ultimate 50-year cost of owning masonry wall 24,000 sq ft x $10.40/80,000 sq ft		3.12 per sq ft
Architects' fee $132,000/80,000 sq ft		1.65 per sq ft
Summary of Ultimate Costs		
Structure	$43.09 per sq ft	
Windows	4.85 per sq ft	
Walls	3.12 per sq ft	
Architects' fee	1.65 per sq ft	
Land	0.00	
	$52.71 per sq ft of rentable floor area	

The interest rate (i) and the number of time periods (N) must be expressed in the same terms -- weeks, months, or years. Interest tables are available with these factors computed for several interest rates. The table for a 6% interest rate is included here as Table 12.

Where an average annual rate of price change (f) is used, the present worth factors must be supplemented by a correction factor which includes this change.

$$P_u = \frac{1}{F_u}\int_0^n \frac{(1 + Nf)\,dN}{(1 + i)^N}$$

Where: P_u is the correction factor for the present worth for a uniformly changing series of future annual expenditures.

F_u is the present worth factor for a uniform series of equal future annual expenditures for n years.

N is time in years.

i is the value of money.

f is the average annual rate of price change.

After specific values are selected for the variables in the above equation, a solution to the integration may be approximated by Simpson's Rule.

Where future costs occur at regular intervals other than annual periods, the cost is calculated by multiplying the present cost (C) by the factor (1 + Nf) and the present worth factor (F_s) for the single future payment. The single payments for the span of time under consideration are added to obtain the total present value of future costs at the non-annual intervals.

When the value of money i is 6%, the present cost of painting is $0.10 per sq ft, and this cost is expected to rise at a rate (f) of 0.0377 per year, the present value of all future painting costs is calculated as follows:

N Year	F_s at 6%	Future Cost c (1 + Nf)	Present Value of Future Costs F_s C (1 + Nf)
4th	0.7921	$0.1151	$0.091
8th	0.6274	0.1302	0.082
12th	0.4970	0.1452	0.072
16th	0.3936	0.1603	0.063
20th	0.3118	0.1754	0.055
Total present value of future painting costs			$0.363

TABLE 12 -- PRESENT WORTH FACTORS, 6% INTEREST RATE

N Year	F_s Single Payment	F_u Uniform Annual Series
1	0.9434	0.943
2	0.8900	1.833
3	0.8396	2.673
4	0.7921	3.465
5	0.7473	4.212
6	0.7050	4.917
7	0.6651	5.582
8	0.6274	6.210
9	0.5919	6.802
10	0.5584	7.360
11	0.5268	7.887
12	0.4970	8.384
13	0.4688	8.853
14	0.4423	9.295
15	0.4173	9.712
16	0.3936	10.106
17	0.3714	10.477
18	0.3503	10.828
19	0.3305	11.158
20	0.3118	11.470
21	0.2942	11.764
22	0.2775	12.042
23	0.2618	12.303
24	0.2470	12.550
25	0.2330	12.783
26	0.2198	13.003
27	0.2074	13.211
28	0.1956	13.406
29	0.1846	13.591
30	0.1741	13.765
31	0.1643	13.929
32	0.1550	14.084
33	0.1462	14.230
34	0.1379	14.368
35	0.1301	14.498
36	0.1227	14.620
37	0.1158	14.737
38	0.1092	14.846
39	0.1031	14.949
40	0.0972	15.046
41	0.0917	15.138
42	0.0865	15.225
43	0.0816	15.306
44	0.0770	15.383
45	0.0727	15.456
46	0.0685	15.524
47	0.0647	15.589
48	0.0610	15.650
49	0.0575	15.708
50	0.0543	15.762

These new factors can be substituted in the appropriate equations to calculate the ultimate costs for the wall construction under the financial conditions imposed.

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Selection of Glass and Solar Shading To Reduce Cooling Demand

by Alfred L. Jaros, Jr., Jaros, Baum & Bolles, Consulting Engineers

Abstract: Solar radiant heat input is evaluated for five types of glasses (single plate, double plate, single heat-absorbing, heat-retarding plate, and laminated heat-reflecting) and for five shading devices (inside light-colored venetian blinds, inside polished aluminum venetian blinds, outside closed awnings, outside open-side awnings, and outside louvers, venetian blinds or shading screens). Comparisons are made of unshaded glasses and of single plate glass with shading devices, giving estimated cost and saving for each. Wet roof operation is also evaluated. It is concluded that if no shading is provided, heat-reflecting or single heat-absorbing glasses should be used; that if shading devices are used, single plate glass with inside venetian blinds is the most economically efficient combination; and that outside shading devices often give the largest thermal savings but are high in installation cost.

THIS PAPER COMPARES AND EVALUATES the constructions used to reduce the input of heat derived from solar radiation through windows, with particular reference to costs of installation, savings in air conditioning load, and consequent net savings in total investment and in evaluated annual cost. For basic data, the selected unit size was one square foot of glass; for application comparisons, it was one horizontal running foot of glass, six feet high. Sash, mullions, muntins, etc., are external to these unit sizes.

Not all possible shading devices could be considered. Some devices, such as fixed concrete vertical louvers or vertical screen walls, must be regarded as architectural treatment. Their patterns, proportions, and costs vary so greatly that it is not feasible to evaluate them generally.

METHODS OF ANALYSIS

The following methods seem most practical for evaluating solar radiant heat input and the various devices for controlling it:

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1. Determine Btu/hr heat input through single plate glass.
2. Determine the difference in Btu/hr transmitted between single plate glass and the particular solar heat rejecting method for one square foot of glass.
3. Make comparisons per horizontal linear foot of glass, six feet high. Computations have been based on glass running continuously for considerable widths, with suitably spaced narrow mullions; these should apply equally to a row of windows or to a really continuous band. For heights other than six feet, one may prorate.
4. Base all computations on net square feet of actual glass. A tentative 15% discount may be made in sizing actual air conditioning equipment for that portion of the total window opening which is not glass.
5. Consider the aggregate sensible heat entering through glass. The ASHRAE Guide (Heating, Ventilating, and Air-Conditioning Guide of the American Society of Heating, Refrigerating and Air-Conditioning Engineers) provides basic data for this evaluation. It has been necessary in this paper to extend the ASHRAE data to other types of glass and shading, but these extensions are believed to be as reliable as the data derived from the ASHRAE Guide.
6. Determine a reasonable installed cost for the particular solar heat rejecting method, assuming that it is to be added to a structurally complete building.
7. Having determined the reduction in heat input resulting from a given type of glass or shading, evaluate the expected saving in installation cost of air conditioning equipment. For the purpose of this paper, it seems reasonable to evaluate such savings at $900/ton of refrigeration or about 65% of present day unit costs of complete installations for typical New York City office buildings of good quality. This figure may be subdivided into $300/ton for the central plant and $600/ton for the distributing systems.
8. Evaluate the probable savings in annual ton-hours of cooling consumption, using data giving the average percentage of sunshine hours and the degree to which the particular glass or shading will exclude sunshine.
9. Consider orientation and configuration. Different orientations produce different figures.
10. Evaluate the annual cooling consumption savings. It seems logical to consider only the costs of electricity, steam, water, etc; not operating labor nor annual maintenance costs. For this paper, 2.5¢/ton-hour of refrigeration per season has been used as a working average.
11. Add to the operating savings the savings in fixed charges -- interest on the investment, amortization, taxes, etc. For this paper, 10% has been used.
12. Add to the annual operating saving the fixed charges on the

net investment saving resulting from the shading method to get the overall annual saving.

COMPUTATIONS

All computations (except for reflecting glass) have been made in accordance with methods and data given in Chapter 13 of the 1960 ASHRAE Guide, pages 195-201. Data received from one manufacturer of reflecting glass have been used for this type.

Data for 40° North Latitude have been used, and the results may be considered sufficiently close for 38° to 43°. Times stated are local sun time.

Solar input figures have been based on very clear weather, which will produce maximum solar heat gain. Reduction because of haze would reduce only the operating savings. Conduction and convection of sensible heat through glass only, owing to difference between indoor and outdoor air temperature, are included in all computations. A maintained indoor dry bulb temperature of 75° F has been used throughout (instead of 80° F as in the ASHRAE Guide), as being more typical of future practice. Instead of a uniform 95° F outdoor dry bulb temperature (as in the ASHRAE Guide), the following outdoor temperatures have been used, as being more typical for a clear summer day:

Time:	0700	0800	0900	1000	1100	1200-1300	1400-1700	1800-1900
Temp:	85°F	86°F	88°F	90°F	92°F	94°F	95°F	94°F

Since tabulations (see Table 1, p. 76) are based on net glass area exposed to sunshine, they should not be multiplied by masonry opening areas without correction. Window frames and sash will conduct in summer only a fraction of what glass would transmit due to direct solar impact. If windows are recessed, the glass directly exposed to sunshine may be reduced to 80% or less of the masonry opening. The correction to be applied should be determined to fit each situation. For this paper, such variable factors have been ignored, since they do not materially affect the comparison between types of glass or shading.

Obviously, factors and constants used would change for more southerly latitudes. Any tabulations to be used at 30°, 20°, or even nearer the Equator, should be reworked, especially for north and south exposures. Installation savings will decrease (on the side toward the Equator only), but operating savings will increase, because there are more annual cooling hours. Figures for Dallas, Texas, have been developed as representing a typical southern United States location (see Table 4, p. 79).

COMPARISON OF TYPES OF GLASS

Figure 1 shows the peak load values for all orientations for five types of glass: Curves 1 - Single plate glass, 1/4 to 3/8 in. thick;

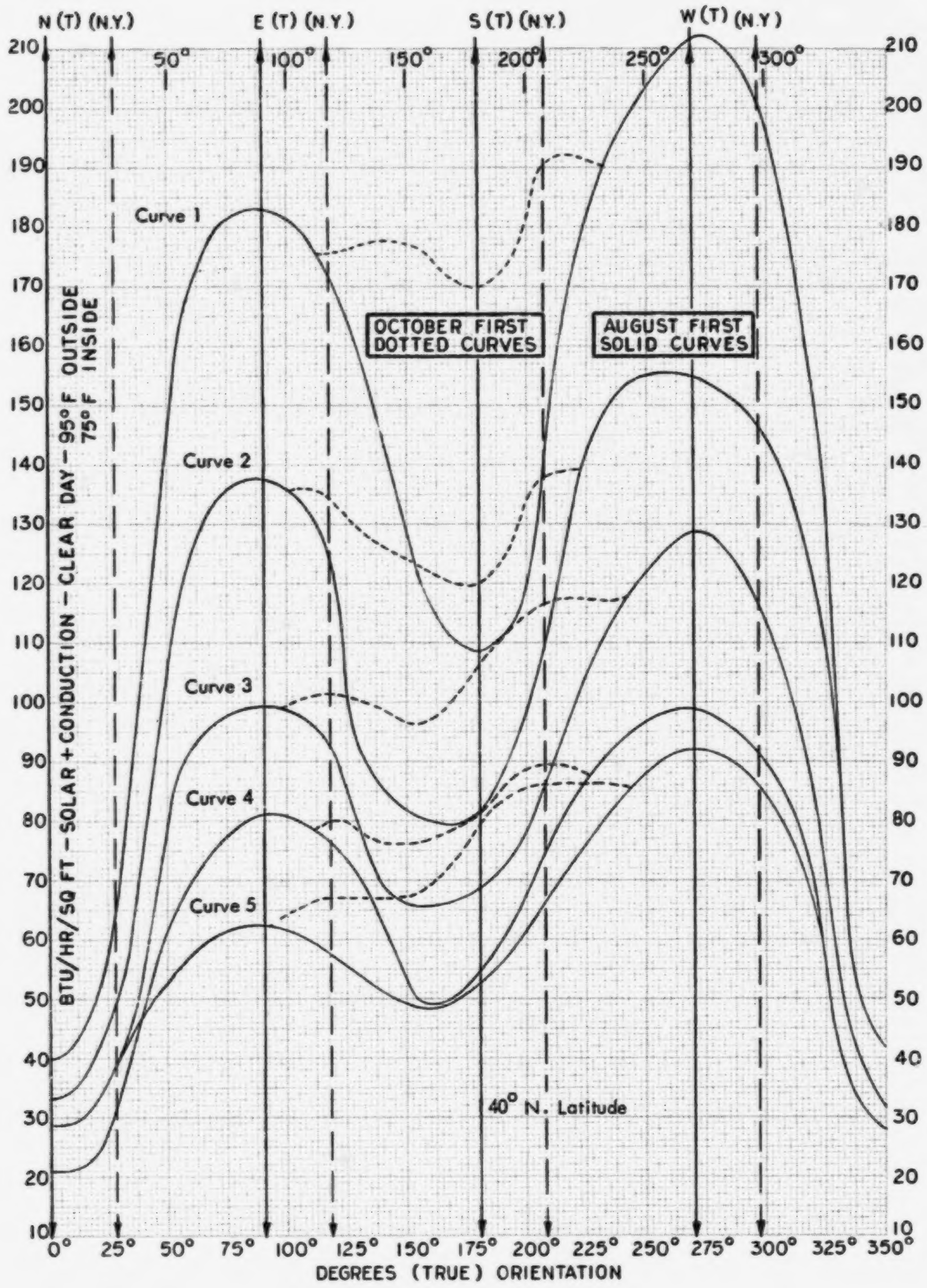

Figure 1 -- Comparison of solar heat conduction through unshaded single plate glass with solar heat conduction through other types of unshaded glass: curve 1, single plate glass; curve 2, double plate glass; curve 3, single heat-absorbing glass; curve 4, heat-retarding glass (double glass with outer layer heat-absorbing); and curve 5, laminated heat-reflecting glass.

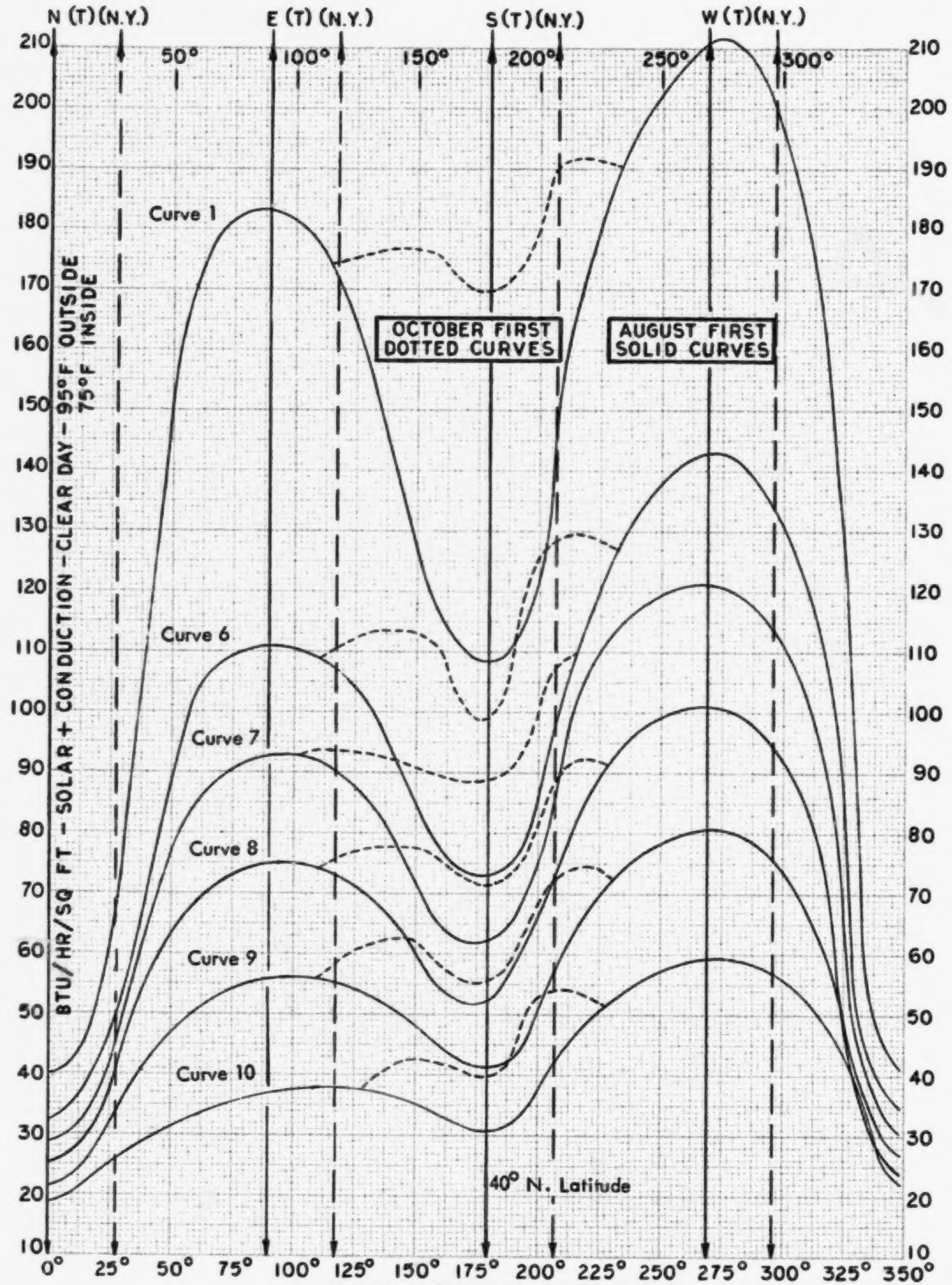

Figure 2 -- Comparison of solar heat conduction through unshaded single plate glass with solar heat conduction through single plate glass shaded with the following devices: curve 6, inside venetian blinds, painted a light color; curve 7, inside polished aluminum venetian blinds; curve 8, outside awnings with closed sides; curve 9, outside awnings with open sides; and curve 10, outside louvers, venetian blinds, or louver-type shading screens.

Curve 2 -- Double plate glass, with sealed air space between; Curve 3 -- Single heat-absorbing glass, 1/4 to 3/8 in. thick; Curve 4 -- Heat-retarding plate glass (double glass with outer layer heat-absorbing); and Curve 5 -- Laminated heat-reflecting glass, with metallized central film.

Heat-retarding plate glass (Curve 4) has proved troublesome, especially in large panes. In summer, when the sun shines, the outer pane reaches a much higher internal temperature than the inner pane; in cold weather, the reverse may be true. Differential expansion can lead to difficulties in preserving the seal, to spontaneous cracking of the glass, or to damage to the sash.

Another practical difficulty with all types of large double panes is a "hothouse effect." In cold sunny weather, the double pane is quite transparent to high-frequency infrared but relatively opaque to outward conduction and radiation from the room. This may necessitate using refrigeration for the sunny side of the building even when the temperature is 25° or 30° F outdoors.

TABLE 1—SOLAR HEAT CONDUCTION OF UNSHADED SINGLE PLATE GLASS [1] ON A TYPICAL BUSINESS DAY (August 1,[2] 40° N. Latitude, in Btu/hr/ft^2)

Sun Time	"True" Orientation (or "Solar Azimuth") in Degrees 0	30	60	90	120	150	180	210	240	270	300	330
0800	11	45	170	183	170	82	14	9	9	9	9	9
0900	11	31	141	167	162	120	38	12	10	10	10	10
1000	17	21	62	121	136	132	70	23	20	20	20	19
1100	24	26	30	66	108	111	95	46	26	26	26	24
1200	32	32	32	34	53	96	108	94	57	34	32	32
1300	35	35	35	35	35	53	104	127	120	73	40	35
1400	36	36	36	36	36	40	87	150	156	140	80	41
1500	35	35	35	35	35	35	61	156	185	190	162	55
1600	34	34	34	34	34	34	38	111	191	212	198	85
1700	34	34	29	29	29	29	30	63	181	202	189	100
1800	40	23	22	22	22	22	24	38	113	138	142	115
Summation	308	352	626	762	820	754	669	829	1072	994	908	525

NOTE: Bold face figures are peak values for those orientations. At certain orientations, higher input for October 1 midday is anticipated: 120° at 1000–165; 150° at 1000–177; 180° at 1400–191; and 240° at 1400–191.

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[1] Data throughout for single plate glass are for thickness of 1/4 to 3/8 in.

[2] August 1 has been selected as a typical time for evaluation of required cooling loads and their comparisons. The only important exception is windows facing in southerly directions (about 135° to 225° true). Maximum demand may occur in October for southward peripheral zones but not for the entire building.

COMPARISON OF SHADING DEVICES

Only five specific curves for shading devices are shown in Figure 2. Each of these is equivalent thermally to various other shading devices, as noted below. All data relating to effects of shading devices are based only on their use with single plate glass, since experience has shown that combinations of heat-absorbing and other special glass with shading devices are uneconomical. Shading from nearby buildings, trees, etc., has necessarily been ignored.

The five curves shown are: Curve 6 -- Inside venetian blinds, painted a light color; Curve 7 -- Inside polished aluminum venetian blinds; Curve 8 -- Outside canvas or dark metal awnings with closed sides; Curve 9 -- Outside canvas or dark metal awnings with open sides; Curve 10 -- Outside white aluminum or stainless steel louvers and venetian blinds; also louver-type reflecting insect screens.

For evaluating other types of shading devices, the following comparisons may be useful:

1. Clear white or pale cream-colored drapes are equivalent to cream-colored inside venetian blinds.
2. Certain grades of white glass-fiber or metallic-coated drapes or roller shades can be as effective as aluminum inside venetian blinds.
3. Dark-colored (or dirty) drapes do not reflect much infrared; their effect might be about equal to double plate glass, unshaded. Really dark drapes or shutters merely convert infrared into sensible heat.
4. The heat-reducing value of outside shading depends largely on its ventilation by air circulation. Light-colored, polished metal outside shading is less dependent on air circulation than canvas or dark finishes.
5. Closed awnings with adequate ventilating openings at the top are about equal to open awnings.
6. Projecting solid balconies or cornices are a little better than open awnings, but only to the extent that they actually shade the glass. (See Table 26, p. 205, of the 1960 ASHRAE Guide for width of projection).
7. Outside louvers, well-ventilated and properly oriented, are the most efficient shading devices for all-round use. On the south, horizontal louvers are efficient; on east or west, vertical louvers are more effective. In general, louvers should be projected appreciably. With such mounting, louvered shading screens will be as effective as outside louvers when the sun is high but every 10° by which the sun's altitude is less than 40° (for the 17-bar/inch type) or 25° (for the 23-bar/inch type) will downgrade their protection to about the next higher curve on the graph (Figure 2).
8. Various types of screen walls may be effective for low buildings on the east and west. The screen wall may be combined with a large cantilevered roof overhang.
9. An interesting device long used abroad but relatively new here is a pivoted sash containing two separate panes of glass, with a venetian blind mounted between. The inner pane is also pivoted and can be swung open. Such windows

are competitive in price with standard single pane windows and inside blinds. They should be effective in reducing transfer of heat and sound, but until adequate data are available evaluation is not feasible.

PRACTICAL LOAD ANALYSIS

Peak cooling demand for the various glass types and shading devices is shown in Figures 1 and 2. The morning peak (August 1) is shown on the line at 90° True; the midday peak (October 1) is shown on the line at 210° True; and the afternoon peak (August 1) is shown on the line at 270° True.

For northeastern United States locations, the seasonal consumption of cooling per square foot of unshaded single plate glass, due only to solar radiant heat, has been evaluated for an office building during business hours in a typical year of 107 business days (see Table 2). It is a complex and largely empiric process to evaluate monthly average cooling loads due to glass. One must take into account solar radiant heat input (which varies with each orientation), changing average monthly air temperature, generally rising temperature during the day, and percentage of sunshine (taken at 63% in Table 2).

TABLE 2—AVERAGE MONTHLY COOLING LOADS FOR ONE SQUARE FOOT OF UNSHADED SINGLE PLATE GLASS IN AN OFFICE BUILDING (40° N. Latitude)

Orientation	Load Basis	May 14 days	June 20 days	July 20 days	Aug. 21 days	Sept. 20 days	Oct. 12 days	Total 107 days
0° True	Average Btu/Day	150	250	300	280	250	100	—
	Monthly Sum	1,300	3,200	3,800	3,700	3,200	800	15,800
60° True	Average Btu/Day	300	430	470	450	330	200	—
	Monthly Sum	2,600	5,400	5,900	6,000	4,200	1,500	25,600
90° to 120° True	Average Btu/Day	350	470	520	500	450	350	—
	Monthly Sum	3,100	5,900	6,600	6,600	5,700	2,700	30,600
180° True	Average Btu/Day	400	520	570	600	600	560	—
	Monthly Sum	3,500	5,600	7,200	8,400	7,400	4,200	36,000
240° to 270° True	Average Btu/Day	620	780	850	850	600	500	—
	Monthly Sum	5,500	9,800	10,200	11,400	7,600	3,700	54,200
300° True	Average Btu/Day	520	650	700	700	500	400	—
	Monthly Sum	4,600	8,200	8,400	9,300	6,300	3,000	39,800

Table 2 is based largely on the writer's judgment and experience. A ratio system can sometimes give results close enough for practical use. Table 3 shows a sample of such an analysis.

TABLE 3—SAMPLE ANALYSIS OF AVERAGE COOLING LOADS, USING RATIO SYSTEM, IN NEW YORK AND DALLAS

Criterion	New York	Dallas	Ratio
Cooling needed, months/business days	6/107	12/213	2
Cooling needed, total hr/hr business days	1400/1000	5350/3700	3.7
Cooling equivalent, full load business day hr	600	1750	2.8
Average sunshine, summer/spring-fall	64%/60%	78%/65%	1.22/1.08
Average hours dry bulb temp. over 80°/90°F	597/86	1861/820	3.15/9.5
Average hours wet bulb temp. over 64°/72°F	1832/406	2709/1791	1.48/4.4
Average noon dry bulb temp. summer/spring-fall	75.8°/56.8°	87.3°/70.6°	+11.5°/+13.8°

It may be helpful to visualize the proportions of total cooling demand chargeable to different factors. An evaluation may be based on any desired set of assumptions, such as:

Floor area, 100 sq ft/person
Electric heat, 6 watts/sq ft
Outside air, 0.4 cu ft/min per sq ft
Outside air conditioning, 40 Btu/hr per cu ft/min[1]
Percent glass in façades, 25%, 50%, and 75% (with good inside venetian blinds).

On these assumptions, overall percentages for an entire building can be approximated, as in Table 4. It is assumed that the four façades are more or less equal, that 40% of the floor area is interior zone, and that blinds are drawn only on the side exposed to sunshine.

TABLE 4—PERCENTAGE OF HEAT GAIN FOR ENTIRE BUILDING

Heat Source	Glass in Facade		
	25%	50%	75%
		(Percentage of heat gain)	
People, lights, and office equipment	32	24	19
Window heat input (maximum)	32	47	57
Conditioning of outdoor air	20	15	12
Conduction through walls	4	3	2
Miscellaneous allowances	12	11	10
Total	100	100	100

By combining the ratios in Table 3 with estimated cooling loads and assuming equal electric and steam rates, application ratios for Dallas vs. New York City would approximate 3x for total operating cost and 2.0 to 2.3x for window solar operating cost, varying with orientation (see Table 5).

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[1] This corresponds to about 75° F outside wet bulb temperature; 77° F and 50% relative humidity or 79° F and 45% relative humidity, inside.

TABLE 5—ANNUAL TON-HOURS PER SQUARE FOOT OF GLASS, NEW YORK AND DALLAS

Glass and Shading	0° T.		60° T.		90 to 120° T.		180° T.		240-270° T.		300° T.	
	New York	Dallas	New York	Dallas	New York	Dallas	New York	Dallas	New York	Dallas	New York	Dallas
Single Plate, no shading	1.30	3.25	2.20	5.00	2.60	5.60	3.00	6.00	4.50	9.70	3.30	7.60
Double Plate, no shading	0.80	2.00	1.70	3.90	2.10	4.50	2.40	4.80	3.25	7.00	2.40	5.50
Single Plate Heat Absorbent, no shading	1.00	2.50	1.20	2.75	1.45	3.10	1.85	3.70	2.75	5.90	2.00	4.60
Single Plate Heat Absorbent + Single Plate, no shading	0.60	1.50	0.95	2.20	1.20	2.60	1.40	2.80	2.10	4.50	1.55	3.50
Single Plate Heat Reflecting, no shading	0.60	1.50	0.75	1.70	0.95	2.05	1.35	2.70	1.95	4.20	1.45	3.30
Single Plate, light inside Venetian blinds	1.10	2.75	1.35	3.10	1.60	3.45	2.05	4.10	2.75	5.90	2.00	4.60
Single Plate, alum. inside Venetian blinds	1.00	2.50	1.15	2.60	1.40	3.10	1.75	3.50	2.45	5.25	1.75	4.00
Single Plate, closed outside awnings	0.60	1.50	0.90	2.05	1.10	2.35	1.40	2.80	1.95	4.20	1.45	3.30
Single Plate, open outside awnings	0.60	1.50	0.75	1.60	0.90	1.95	1.15	2.30	1.50	3.20	1.15	2.60
Single Plate, aluminum outside louvers, etc	0.60	1.50	0.45	1.60	0.55	1.20	0.85	1.70	1.25	2.70	0.95	2.20

COMPARATIVE COSTS OF UNSHADED GLASSES AND SHADING DEVICES

Figures from manufacturers and experienced builders indicate that estimated installed costs of unshaded glass for large buildings are as shown in Table 6. This cost may be prorated for other heights of glass.

TABLE 6 -- ESTIMATED INSTALLED COST
OF UNSHADED GLASS

Type of Glass	Cost per sq ft installed	Cost per foot of glass perimeter for 6 ft height
1/4 in. single plate glass (polished)	$ 1.50	$ 9.00
Double plate glass	3.50	21.00
1/4 in. heat-absorbing glass	2.25	13.50
Double glass, outer layer heat-absorbing	4.29	25.50
Heat-reflecting sheet glass	3.85	23.10
Heat-reflecting plate glass	4.85	28.10

Since direct solar radiation on northern windows is negligible during business hours, comparisons of installed glazing cost vs. air conditioning saving (all per foot glass perimeter) may logically be based on east and west windows August 1 and south windows October 1.

Costs of inside venetian blinds have been similarly estimated at about $1.00 per sq ft for horizontal slats of standard metal types, manually operated; and about $1.50 per sq ft for vertical slats of metal or fabric, with manual operating gear. The choice between horizontal and vertical slats, apart from relative installation costs, is one of esthetics, convenience, and personal preference since thermal results are equivalent. Vertical inside blinds are more complex, more difficult to maintain, and less apt to be properly used.

Estimated costs for inside light metal venetian blinds (see Curve 7, Figure 2) per linear foot of 6 ft high glass perimeter are: Horizontal, $6.00; vertical, $9.00. They may be prorated for other heights. Because of their lower initial cost, horizontal blinds yield apparent savings of about 30% over vertical blinds.

Installation costs have not been estimated for canvas awnings (see Curves 8 and 9, Figure 2), since their use for large modern buildings is rare. For other types of outside shading, data indicate that the costs presented in Tables 7, 8, 9, 10, and 11 may be considered as typical costs per foot of glass perimeter for large buildings. Note that unit costs vary with height of window, so that prorating is not always feasible.

TABLE 7 -- ESTIMATED COSTS FOR POURED-IN-PLACE REINFORCED CONCRETE SHADING BALCONIES[1]

Projection	Cost per Foot of Glass Perimeter		
	Balcony	Flashing and Drainage	Total
5 ft	$14.00	$4.00	$18.00
6 ft	17.00	4.00	20.00
7 ft	20.00	4.00	24.00
8 ft	24.00	4.00	28.00
9 ft	30.00	4.00	34.00

[1] With flashing at wall, gutters, and drains, but no separate waterproofing, railings, or doors.

On October 1 at about 41° N. Latitude, such a balcony, not more than one foot above the window, will completely shade a south window one foot shorter than the balcony projection (Curve 9, Figure 2). For Dallas at 33° N. Latitude, nearly 2 feet less projection would be needed. If balconies are to be used other than for shading, doors and railings would add further cost.

TABLE 8 -- ESTIMATED COSTS FOR CANTILEVERED ALUMINUM HORIZONTAL LOUVERED CANOPIES[1]

Projection	Cost per Foot of Glass Perimeter
4 ft	$17.00
5 ft	20.00
6 ft	25.00
7 ft	32.00
8 ft	40.00

[1] Cost includes brackets but not structural changes in building wall.

On October 1 at about 41° N. Latitude, such a canopy, close above the window, will shade an equal height of south window (Curve 10, Figure 2). For Dallas, nearly 2 feet less projection would be needed.

Estimated costs for continuous vertical reinforced concrete fins about 10 to 14 ft apart, supporting interrupted groups of horizontal 6 in. louvers (or wider) set in a vertical plane are shown in Table 9. With 6 ft. windows, this device limits outlook considerably; with higher windows, no outlook would remain (Curve 10, Figure 2).

TABLE 9 -- ESTIMATED COSTS FOR CONTINUOUS VERTICAL REINFORCED CONCRETE FINS

Window Height	Approx. Sill Height	Fin Projection	Louver Height (at each level)	Cost per Foot of Glass Perimeter		
				Concrete	Louvers	Total
4 ft	4 ft	1 ft	5 ft	$1.00	$18.00	$19.00
5 ft	4 ft	2 ft	7 ft	2.00	25.00	27.00
6 ft	3 ft	3 ft	10 ft	3.00	36.00	39.00

Estimated costs based on foot of glass perimeter for manually adjustable horizontal outside louvers and for louvered shading screens (4 to 8 ft wide) are shown in Table 10 (Curve 10, Figure 2).

TABLE 10 -- ESTIMATED COSTS FOR OUTSIDE HORIZONTAL ALUMINUM LOUVERS AND LOUVERED SHADING SCREENS

Window Height	Horizontal Louvers	Louvered Shading Screens	
		17-bar/inch	23-bar/inch
4 ft (6 in. vanes)	$24.00	$18.00	$22.00
5 ft (6 in. vanes)	27.00	22.50	27.50
6 ft (9 in. vanes)	31.00	27.00	33.00
7 ft (12 in. vanes)	42.00	31.50	38.50
8 ft (14 in. vanes)	60.00	36.00	44.00
9 ft (14 in. vanes)	65.00	40.50	49.50

Costs of louvers are stated only for manual adjustment by individual bays. Horizontal louvers or blinds will be best for south windows; vertical ones, for east and west windows.

Vertical louvers come in many designs. For all but the smallest, automatic operation is much to be preferred. Automatic control

TABLE 11 -- ESTIMATED COSTS FOR HIGH QUALITY VERTICAL LOUVERS

Vane Size	Type of Control	Height up to	Cost per Sq. Ft.	Sample Window Ht.	Cost per Linear Ft.
9"	Manual	6'	$5.50	4' & 6'	$22 & $33
9"	Automatic	6'	6.00-6.50	4' & 6'	25 & 37
14"	Manual	8'	$5.00	7' & 8'	35 & 40
14"	Automatic	8'	5.40-6.00	7' & 8'	39 & 45
20"	Manual	10'	3.50	9'	31.50
20"	Automatic	10'	3.75-4.00	9'	35.00
20"A[1]	Manual	Over 10'	4.50	20'(2-St.)	90.00
20"A[1]	Automatic	Over 10'	4.75-5.00	20'(2-St.)	97.00

[1] Airfoil double-wall vanes.

costs vary so much that a better approach would be to allow $1,000 to $1,500 beyond estimated costs for manual control for each large group.

Larger and fewer vanes give a cheaper unit cost. The larger vane sizes may also be used efficiently for lower heights than those shown in Table 11, but the increased ratio of mounting and gearing to the vane area would bring unit cost per square foot nearer to that of the next smaller vanes.

None of the unit costs include accessory items such as framing in walls for attachment, extended sills, and scaffolding. These will add a small percentage.

ESTIMATED SAVINGS

Evaluated savings may now be estimated, based on the above costs; some values are tabulated in Table 12, which expresses comparisons for east, south, and west orientations. Relative applicability of these figures depends on the relative proportions of the façades. The saving in air distributing systems is an integrated average for the four directions. Total operating saving approximates the total of those for all directions.

WET ROOFS

Wetting a roof during sunlit hours is a means of reducing the intake of solar radiant heat into a building, the evaporation of water removing about 1050 Btu/hr as latent heat. Obviously, the possible savings are greater for a low widespread industrial building than for the upper floor of a tall office building.

TABLE 12—ESTIMATED SAVING IN AIR CONDITIONING COST THROUGH USE OF DIFFERENT TYPES OF GLASS AND SHADING DEVICES

6' High Window/Ft. Wide Type of Glass and Shading	Cost of Scheme		Differential at $900/T		Net Investment Saving	Estimated Annual Ton Hours		At 2.5¢ / T.Hr. Annual Operating Saving		Including 10% Financing Charges Annual Total Saving	
	Net	Diff.	Refrig. Tons	Saving		NYC	Dallas	NYC	Dallas	NYC	Dallas
EAST											
Single Plate, no shading	$ 9.00	$	—	$	$	15.6	33.6	$	$	$	$
Double Plate, no shading	21.00	12.00	.0235	21.15	9.15	12.6	27.0	0.08	0.17	1.00	1.09
Single Plate Heat-Absorbent, no shading	13.50	4.50	.0413	37.20	32.70	8.6	18.6	0.18	0.38	3.45	3.65
Single Plate Heat-Absorbent + Single Plate, no shading	25.50	16.50	.0510	45.75	29.25	7.2	15.6	0.21	0.45	3.13	3.37
Reflecting Sheet, no shading	23.00	14.00	.0600	54.00	40.00	9.1	19.6	0.26	0.56	4.26	4.56
Reflecting Plate, no shading	29.00	20.00	.0600	54.00	34.00	9.1	19.6	0.26	0.56	3.66	3.96
Single Plate, inside horizontal Venetian blinds	15.00	6.00	.0450	40.50	34.50	8.4	18.6	0.18	0.38+	3.63	3.83
Single Plate, inside vertical Venetian blinds	18.00	9.00	.0450	40.50	31.50	8.4	18.6	0.18	0.38	3.33	3.53
Single Plate, outside vertical automatic louvers	46.00	37.00	.0720	64.80	27.80	3.3	7.2	0.32	0.64	3.10	3.42
Single Plate, 23-bar louvered screen	42.00	33.00	.0680	61.20	28.20	4.5	9.8	0.28	0.60	3.10	3.42
SOUTH											
Single Plate, no shading	9.00	—	—	—	—	18.0	36.0	—	—	—	—
Double Plate, no shading	21.00	12.00	.0266	23.85	11.85	14.4	28.8	0.09	0.18	1.27	1.36
Single Plate Heat-Absorbent, no shading	13.50	4.50	.0368	33.15	28.65	11.1	22.2	0.17	0.35	3.03	3.21
Single Plate Heat-Absorbent + Single Plate, no shading	25.50	16.50	.0510	45.75	29.25	8.4	16.8	0.24	0.48	3.16	3.40
Reflecting Sheet, no shading	23.00	14.00	.0530	47.50	33.50	8.7	17.4	0.25	0.50	3.60	3.85
Reflecting Plate, no shading	29.00	20.00	.0530	47.50	27.50	8.7	17.4	0.25	0.50	3.00	3.25
Single Plate, inside horizontal Venetian blinds	15.00	6.00	.0403	36.30	30.30	10.5	21.0	0.19	0.38	3.22	3.41
Single Plate, inside vertical Venetian blinds	18.00	9.00	.0403	36.30	27.30	10.5	21.0	0.19	0.38	2.92	3.11
Single Plate, outside horizontal manual louvers	40.00	31.00	.0691	62.10	31.10	5.1	10.2	0.32	0.64	3.43	3.75
Single Plate, outside vertical fins and fixed louvers	48.00	39.00	.0691	62.10	23.10	5.1	10.2	0.32	0.64	2.63	2.95
Single Plate, outside horizontal balconies	33.00	24.00	.0590	53.00	29.00	6.9	13.8	0.28	0.56	3.18	4.06
Single Plate, outside hoizontal balconies (Dallas)	27.00	18.00	.0590	53.00	35.00						
Single Plate, outside horizontal louvered canopy	34.00	25.00	.0691	62.10	37.10	5.1	10.2	0.32	0.64	4.03	5.15
Single Plate, outside horizontal louvered canopy (Dallas)	26.00	17.00	.0691	62.10	45.10						
Single Plate, 17-bar louvered screen	36.00	27.00	.0660	59.00	32.00	6.4	12.8	0.31	0.62	3.51	3.82
WEST											
Single Plate, no shading	9.00	—	—	—	—	27.0	58.2	—	—	—	—
Double Plate, no shading	21.00	12.00	.0286	25.65	13.65	19.5	42.0	0.19	0.41	1.55	1.77
Single Plate Heat-Absorbent, no shading	13.50	4.50	.0413	37.20	32.70	16.5	35.4	0.26	0.57	3.53	3.84
Single Plate Heat-Absorbent + Single Plate, no shading	25.50	16.50	.0566	51.00	34.50	12.6	27.0	0.37	0.78	3.82	4.23
Reflecting Sheet, no shading	23.00	14.00	.0610	55.00	41.00	13.5	29.0	0.33	0.72	4.43	4.82
Reflecting Plate, no shading	29.00	20.00	.0610	55.00	35.00	13.5	29.0	0.33	0.72	3.83	4.22
Single Plate, inside horizontal Venetian blinds	15.00	6.00	.0508	45.60	39.60	14.7	31.5	0.31	0.67	4.27	4.63
Single Plate, inside vertical Venetian blinds	18.00	9.00	.0508	45.60	36.60	14.7	31.5	0.31	0.67	3.97	4.33
Single Plate, outside vertical automatic louvers	46.00	37.00	.0878	78.80	41.80	7.5	16.2	0.49	1.05	4.67	5.23
Single Plate, 23-bar louvered screen	42.00	33.00	.0835	74.80	41.80	9.5	20.5	0.44	0.95	4.62	5.13

Data indicate that during mid-afternoon on a clear July-August day, the sun may heat the surface of fireproof masonry roofs to 50° F or more above the indoor temperature and that wet roof surfaces will reduce this temperature-differential to about 14° F. A cumulative total of the temperature-differential between 0800 and 1800 amounts to about 385 degree hours for a dry roof as against about 85 degree hours for a wet roof at 41° N. Latitude. On such a basis, possible savings can be approximated as follows:

TABLE 13 -- ESTIMATED SAVING IN AIR CONDITIONING THROUGH WETTING THE ROOF SURFACE

	Assumed U Value of Complete Roof			
Criterion	0.12	0.16	0.20	0.24
Tons demand/square (100 sq ft), dry	.0500	.0667	.0835	.100
Tons demand/square (100 sq ft), wet	.0140	.0187	.0235	.028
Tons demand difference due to wetting	.036	.048	.060	.072
Air conditioning investment saving at $900/ton (differential)	$32.40	$43.20	$54.00	$64.80
Daily ton hour saving/ square (clear weather	0.3	0.4	0.5	0.6
Seasonal ton hour saving/ square	20.0	26.0	33.0	40.0
Annual operating saving/ square, at 2.5¢/ton hour	$0.50	$0.67	$0.84	$1.00
10% fixed charges on air conditioning investment	3.24	4.32	5.40	6.40
Total annual saving/square, on air conditioning	$3.74	$4.99	$6.34	$7.40

A comparable study for the Dallas area indicates that investment savings would be 1/3 greater and annual operating savings in ton hours should be about 4.5x greater in Dallas than the saving shown in Table 13.

From the saving shown in Table 13 must be subtracted the fixed charges on the installation cost of equipment for keeping the roof wet when the sun shines, plus operating and maintenance costs for this equipment, cost of water, and possible chemical treatment of the water, etc. These figures will vary widely.

Reasonable cost criteria derived from some actual installations not requiring any costly treatment of the available water are shown in Table 14.

TABLE 14 -- COMPARISON OF COSTS FOR ROOF SPRAY SYSTEMS IN NEW YORK CITY AND DALLAS

Cost Item	Cost of Spray System	
	New York City	Dallas
Spray water annual cost at 3¢ per 100 gal.	45¢/square/season	$2.07/square/season
Pumping cost at 1.66¢ kwh	5¢/square/season	24¢/square/season
Investment cost for large installation[1]	$15.00/square	$17.00/square
Total annual cost[2]	$2.10/square	$4.21/square

[1] Does not include basic water supply or treatment.

[2] Includes 10% fixed charges and 10¢/square maintenance charges for spray system.

Combination of the data in Table 13 and 14 for a roof with a U value of 0.20, for example, results in the figures presented in Table 15.

TABLE 15 -- COMPARISON OF SAVINGS RESULTING FROM USE OF ROOF SPRAY SYSTEMS IN NEW YORK AND DALLAS

Saving Item	Saving for Roof with U Value of 0.20	
	New York City	Dallas
Saving in air conditioning investment, minus cost of spray system	$39.00/square	$55.00/square
Air conditioning saving	$0.84/square	$3.86/square
Spray system operating cost	0.60/square	2.51/square
Net operating saving	$0.24/square	$1.35/square
10% fixed charge saving	3.90/square	5.50/square
Total annual saving	4.14/square	6.85/square

Large savings may be possible or there may be an actual net loss. Each case must be individually studied. Roof spray equipment may prove easier to operate and maintain than flooding; flooding may be cheaper if frequent rain occurs between sunny periods. Availability of good quality water as a waste from industrial uses may be a deciding factor in choosing the wet roof operation. Unfortunately, desert-like locations where wet roofs can effect the

the largest air conditioning savings, are frequently places where water for such purposes is either unobtainable, too costly, or in need of much chemical treatment to avoid stains from deposits on roofs.

SUMMARY

The material presented here does not cover all possible shading devices and certainly not all locations. In most cases, however, a simple set of correction factors will adapt the graphs and tables to the particular situation.

These definite trends and relationships have been adequately demonstrated:

1. If no shading is provided, some better type of glazing than single plate glass is economically justified.
2. Thermally, the new heat-reflecting glasses result in greater saving in air conditioning load than any other glass.
3. Theoretically, the combination of outer heat-absorbing glass and inner plate glass offers somewhat greater savings than heat-absorbing glass alone. However, there are serious mechanical and maintenance objections to this combination, especially for large panes.
4. The overall best choices for unshaded windows appear to be heat-reflecting and single heat-absorbing glasses. At a smaller increase in initial glazing cost, these afford almost as large a reduction in air conditioning demand and operating costs as the combinations, without their practical disadvantages.
5. If shading devices are to be used effectively, single plate glass will usually offer the most economical combinations. Surprisingly often, a venetian blind (preferably of aluminum, white plastic, or similar finish) is the most commercially efficient shading device. It is simple, low in initial cost, easy to use and maintain, and economical.
6. Vertical inside blinds, especially fabric ones, and drapes can usually be justified only on esthetic grounds. Their cost is high, efficiency is often low, and frequently maintenance is difficult.
7. Outside shading devices, wisely selected and properly used, frequently give the largest thermal saving. However, their cost of installation is so high that the net result is sometimes not as attractive as the thermal aspect would imply. If other use is to be made of outside balconies facing south, the thermal results (therefore not being charged with the full installation costs) would be most attractive.

Study of Table 12 will show that properly used interior horizontal venetian blinds can be expected to earn annually from one-half to three-fourths of their initial cost. Relatively speaking, this is not true of outside devices. If our criterion, instead, is the total building investment, we find that nearly all good outside shading devices will reduce the total investment by at least twice their cost of installation.

Further study of Table 12 indicates that, for office buildings at least:

1. For west windows, single plate glass with automatically controlled vertical outside louvers offers the largest evaluated annual saving. Louvered shading screens, heat-reflecting glass, vertical inside venetian blinds, and single unshaded heat-absorbing glass follow in that order.
2. For east windows, heat-reflecting glass gives the largest overall annual saving. Horizontal inside venetian blinds, automatic vertical outside louvers, louvered shading screens, vertical inside blinds, and unshaded heat-absorbing glass follow in that order.
3. For south windows, at 41° N. Latitude, cantilevered louver canopies are best (within their size limits). Then come heat-reflecting glass, horizontal inside blinds, louvered shading screens, outside balconies with projecting fixed louvers, and manual control outside aluminum horizontal louvers. At 33° N. Latitude, balconies and louvered shading screens take second place.

Still more efficient formulations of heat-reflecting glasses are being developed. Their evaluation must await data on their performance, cost, and durability.

Open Forum Discussion

Moderator: C. Theodore Larson, Professor, College of Architecture and Design, University of Michigan

Panel Members: Messrs. Jaros, Kling, McLaughlin, and Queer

Mr. Larson: Mr. Kling, have you found that you've been hampered in any way in your control of solar energy because of building codes?

Mr. Kling: The only code that bothers us is the one regarding the large percentage of glass required in schools. If you have a limited site and your buildings are oriented east-west, you are required to have this large percentage of glass and the pupils live behind venetian blinds most of the time, without even the view they might get from a smaller glass area.

Mr. Larson: Isn't it true that dirty windows have an economic advantage, as well as a practical advantage?

Mr. McLaughlin: Dirty glass will absorb solar radiation. This is a good area for research. If we understood how dirt particles are attracted to, and cling to, the glass surface, I am sure that the treatment for avoiding this would be indicated. We prefer having clean glass instead of resorting to dirty glass as a heat absorber.

Mr. Larson: Why can't windows be developed that won't require frequent washings or perhaps no washing at all? Have your studies pointed in that direction?

Mr. Queer: A surface can be put on the glass that has very little retention power for dirt. For example, it is possible to make plastic coatings that will release dirt. They have a very low friction and low static charge attraction. I believe that this is one of the potential developments that may help to cut the maintenance cost or cleaning cost on glass in big buildings.

Mr. Larson: Mr. Jaros, which do you personally prefer, the glasses that stop solar radiation or mechanical devices that will do the same job?

Mr. Jaros: This is not a question that can be answered with a simple yes or no. For example, we had a large public library in which the main lobby was an architectural and decorative feature of the city. This had windows 15 or 18 feet high, facing southward. These windows had to be completely unobstructed by blinds, drapes, or anything else so that the city, so to speak, could look into the library day and night. In this particular case, the obvious answer was to put in heat-retarding glass.

On the other hand, I can think of a 10-story office building in the tropics, in an area of South America where we have 110° in the shade in the summer and never have winter. In spite of the high humidity and intense sun, the air-conditioning load and costs are less per square foot than for a corresponding building in New York or Washington. The architect put vertical fins 20 feet apart at each column, projecting 4 or 5 feet outward, and between those fins he hung banks of 12 inch wide fixed horizontal aluminum louvers set at about 45°. The louvers were so located that the occupants could look out diagonally downward and see the country side, yet during the hottest parts of the year, no sunshine hit the glass. The building was a long narrow building with the two principal façades facing north and south. Being within a few degrees of the Equator, in our summer it got the sun on the north side and in our winter it got the sun on the south side, but both sides were so completely shaded that the actual cooling tonnage and costs were lower than for ordinary buildings here. This was obviously a case where the outside shading device was the right answer. Under some of our building codes you could not have designed that kind of a building because of objection to the possible wind effects or other concomitants of the large louvers.

Mr. Wright: Please comment on the use of a 100% glass wall.

Mr. Jaros: In Lever House, we had the nearest to a building with a continuous glass wall, but at the points where the floor slabs came in, the glass wall was merely an outer finish. That part of the glass was completely neglected as far as solar transmission was concerned in figuring the air conditioning loads. The job works. My point is that even though a building may look as if it is 100% glass, it can never be anything approaching a 100% glass from the thermal point of view.

Mr. McLaughlin: We had a problem on a building where the structure was faced with glass from the ground to the fourth deck. The heat gained between the glass and the structure was a heat gain that we had not provided for. It didn't reradiate back out from the structure but was conducted into the structure and our air conditioning was not adequate.

Mr. Jaros: In Lever House, the air conditioning was adequate. Possibly they put insulation between the glass and the concrete.

Mr. Kling: The reradiation effect is something you would have to examine with each problem, but is it as bad in a metal solar barrier as it is in other barriers?

Mr. Jaros: It doesn't have to be bad in a metal barrier at all, because in effect you can use a louver canopy - a horizontal frame carrying a series of louver blades with air space between. Since these are of polished metal and are inclined outward, the sun heat is largely reflected. Even so, some of it is absorbed by the metal and then carried away by convection between the blades. I much prefer a louver canopy to a solid balcony for that reason. Actually the costs are about the same.

Donald J. Vild, Libbey-Owens-Ford Glass Company: In the Carrier System Design Manual, it is shown that the solar heat gain through heat-absorbing double glazing is about 65% of that for single heat-absorbing glass, each with light venetian blinds inside. You indicated this is not correct. Can you explain this disagreement?

Mr. Jaros: The curves I prepared were worked out by following what was given in the ASHRAE Guide. The ASHRAE Guide is based on net glass and goes into a great many factors that are more complex to handle mathematically than the Carrier manual. The Carrier method and the ASHRAE method evidently do not agree.

Mr. Vild: The ASHRAE Guide contains no data for any insulating glass in combination with shading device. You also compared types of glass and shading devices which are not in the ASHRAE Guide.

Mr. Jaros: The only such type of glass that I know of was the reflecting glass, on which we got data from the manufacturers corresponding to all the coefficients in the ASHRAE Guide and used them. As far as shading devices are concerned, we took data entirely from the ASHRAE Guide but then made the assumption that an outside venetian blind or an outside louver of the same finish will do the same work, both of them being external reflecting surfaces. Actually, you will find that my five curves of shading devices correspond to headings in the ASHRAE Guide and that the rest is an attempt to evaluate those in terms of other types of shading devices.

J. H. Stuart, Merck Sharp & Dohme: Professor McLaughlin, The Ultimate Cost of Building Walls, published by the Structural Clay Products Institute, presented data at considerable variance with your own. Are you familiar with this publication, and if so, can you explain the differences?

Mr. McLaughlin: Yes, the figures are quite different. Our figures are of the magnitude of $54. I think the figures in the SCPI publication were around $16. There are two additional factors involved in the summation. One was credit for a reduction in illumination and another was credit for the reduction in heat load because of good control of the lighting. The principal reason for the difference in the magnitude of the costs is that our figures represent the entire building, expressed on a basis of square foot of rentable area. This, we believe, is a more translatable figure than one which reflects only the cost of the panels.

Mr. Hudspeth, Libbey-Owens-Ford Glass Company: In figuring costs, what about the changes in glass prices?

Mr. Kling: Some of the figures that are given on a unit price for glass are quite misleading. It has been our experience that in the average building, when we use really effective heat-absorbing glass, much of the hoped-for saving in Btu's is counteracted by the extra cost of glazing. For example, as the glass heats, it generates such a high temperature that it cooks up the gasketing. Since the gasketing is confined, an air pressure develops between the gasket and the frame and blows the gasket right out of the window. This means you have to devise a snorkel system to release gas pressures in this type of glazing. The other objection is the reradiation effect of a heat-absorbing sheet of glass. After this glass has picked up solar energy, it reradiates it and makes a band of radiant heated space around a building quite untenable for people. This is one reason we are experimenting with the use of heat-absorbing glass to pick up the Btu's outside of the building environment. We hope to carry away some of this energy by convection and to carry away more of it by conduction into the framing which supports it. Mr. Jaros says to take only two-thirds of the yield in savings on the cooling system for the building. Until we have a few buildings with heat-absorbing glass in service -- the total system functioning as a building with people in it -- we are inclined not to take any credit on the cooling system.

Mr. John M. Evans, Florida Architect: I've heard that radiant air conditioning would soon be in production. Do you know anything about radiant air conditioning?

Mr. Jaros: This has already been done. The late Charles Leopold made a pilot installation at Radio City over ten years ago, using extruded aluminum shapes through which cold water was circulated from a small refrigerating plant. On the basis of his work and that of a Swedish engineer named Fraenger, we ultimately were able to design a 30-story building for Alcoa in Pittsburgh, which has been successfully operating for several years. Leopold also did some large buildings in Toronto. There are at least 4 or 5 buildings in existence today on a large scale, as well as cafeterias, factories, and other places of that sort, using radiant air conditioning.

The basic idea is this: you have a metal ceiling which is cooled to a certain temperature, such as between 60° and 65° F. You maintain the dew point in the conditioned spaces at lower than that, probably 56° or so, and carefully controlled to avoid condensation troubles. The ceiling will absorb 20 to 25 Btu's per square foot of sensible heat under average room conditions and more than that when the sun is shining into the room and heating the floor. In addition to this, it will absorb a great deal more heat than this from light fixtures mounted in the ceiling. You can get along with about half as much air to cool as you could if you cooled entirely with air. Furthermore, since the water flow in the ceiling is controllable, you don't have to zone the air.

We have used this system in several jobs. I expect we will use it more in the future, but the choice depends upon a lot of factors, one of which is window size. In a building with large windows, the ceiling can do so little of the total cooling that you are faced with paying for the ceiling system and almost as large a duct system in addition. In a building with very small windows, it sometimes becomes the most economical of all systems. In fact, the South American office building mentioned earlier was designed with this sort of cooling. It proved cheaper than more conventional cooling because we kept the sun off the glass.

Mr. Evans: Dehumidification is a problem. Obviously, your radiant heat exchangers will not do the job, so how does the dehumidification work?

Mr. Jaros: You still have to deliver air to the space, but you deliver much less air and that air has to be dehumidified enough to keep the dew point in the space below the temperature of the ceiling and the connecting piping. To give actual figures, in the Alcoa Building we figured on 60° as the minimum chilled water temperature circulating through that part of the system. The ceiling itself was about 63°. Aluminum being a very good conductor, you can get the metal to within 2° or 3° of the water temperature. The dew point was held to about 56°, with good control on the ventilating system. One of the features we used was a special type of control which would cut off the chilled water circulation if the dew point ever got to 58°.

Design of Windows

by J. W. Griffith, Southern Methodist University

Abstract: This paper deals with the effects of window design on human environment. The quantity and quality of heat and light distribution through windows depend on the availability of daylight and on solar radiation. Reflected glare is a complex problem. Daylighting on the task coming from large angles of incidence and indirect lighting greatly reduce disability glare caused by specular reflection. Double glazing is preferred to single glazing, because it keeps out drafts, maintains a relative humidity of 30% to 40%, reduces condensation on the inside of the glass, and keeps out noise. Daylighting is economical; there is less heat per foot-candle for daylighting than for electric lighting. Windows are also a safety factor in case of fire.

THE DESIGN OF WINDOWS involves more than mere technical data on transmittance, size, and location. All too often the designer thinks of windows only as a heat and light source rather than as a complex design tool that can add beauty, quality, and variability to the environment. This paper presents some of the effects of window design on the human environment.

QUANTITY OF HEAT AND LIGHT TRANSMISSION

In quantitative analysis of window design, the amount of heat and light transmittance may vary from zero to 100% transmittance, as in the case of a clear opening. In general, the total amount of light or heat transmitted through any one type of material will be approximately proportional to the size of the window. The usability and the desirability of this light or heat can be made to vary considerably, depending upon the type of control. The effects of heat transmission through windows with and without controls can be obtained from the Heating, Ventilating, and Air Conditioning Guide (1).

Unfortunately, there is no one guide giving the transmittance and effects of light distribution through various types of windows

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GRIFFITH, JAMES W. Professor, School of Engineering, Southern Methodist University; member, American Society for Engineering Education, BRI, Illuminating Engineering Society, and National Society of Professional Engineers. Served on International Commission on Illumination.

and controls. Most of the research work on daylighting in the United States has been reported in the Illuminating Engineering magazine, notably on effects of controls for windows employing flat glass (11, 12, 13, 14, 15, 20, 21) and effects of transmission and light distribution with glass block fenestration (4, 5, 22, 23).

The window area near the top of the wall contributes more direct illumination to the interior of the room than the lower portion, which usually contributes more indirect illumination. To obtain the best utilization of daylight, the window area should be wall to wall and from the ceiling down to the floor. Some interior designs require a sill, in which case it should be held at a minimum height.

In designing windows, air conditioning is sometimes out of the question and natural ventilation must be relied on. Naturally, the heat load or loss through the windows and its control contribute considerably to this thermal environment, and it is also affected by the natural ventilation (6, 7, 16, 24, 25, 26).

Heat and light distribution through windows from outdoors to indoors is directly dependent upon the availability of daylight and solar radiation. Solar radiation data is readily available from U.S. Weather Bureau reports, but data on the availability of daylighting is rather limited (see the Illuminating Engineering Society Lighting Handbook (17) and the IES Recommended Practice for Daylighting (18)). Extensive surveys have been made on the availability of daylight in Port Allegheny, Pennsylvania, and Ann Arbor, Michigan (3, 19). Many more such studies are needed.

QUALITY OF HEAT AND LIGHT TRANSMISSION

An even more interesting aspect of solar transmission through windows is the effect on quality of heat and light transmission.

Double glazed windows permit the utilization of daylighting within the room without uncomfortable drafts. If the ideal environment in cold climate is economically desirable, some form of double glazing must be used. In extremely cold climate, relative humidities higher than 12% to 13% are impractical with single glazing. With double glazing the relative humidity can be maintained in the range of 30% to 40% under similar conditions. An additional benefit with double glazing is the reduction of condensation on the inside surface.

The luminous effect of windows on the quality of the visual environment may be even more beneficial. This is particularly true where the completely controlled environment is not practical. It is easily demonstrated by the effect of side wall lighting on reflected glare.

Illumination from windows is both direct and indirect. Indirect lighting reduces the disability glare caused by specular reflectance. Even the direct lighting can greatly reduce the loss of contrast in a task caused by specular reflectance. Blackwell (2) has shown that for each 1% loss in contrast owing to reflected glare, an increase of 15% in the illumination level must be obtained to give equal performance on a typical task of black pencil on white paper, if the illumination level is near that recommended by the Illuminating Engineering Society for this task. Chorlton and Davidson (8) have shown that a 13% contrast reduction can often occur in classrooms, owing to reflected glare.

Daylighting coming from large angles of incidence on the task helps overcome the effect of specular reflection, when the window is not in the specular angle of view. The daylight illumination from the side wall is extremely valuable in overcoming disability glare. Even if the window wall is in the specular angle of reflection, the brightness can be controlled by adjustable horizontal louvers.

EFFECT OF REFLECTED GLARE

The effect of specular reflection on a task can be calculated by computing the loss of contrast owing to reflected glare caused by the mirrored image of a direct lighting fixture located above and in front of the normal viewing task. Contrast is numerically defined by the equation:

$$C = \frac{B_1 - B_2}{B_1}$$

where B_1 = brightness of background and

B_2 = brightness of object.

When specular illumination and diffuse illumination are present, this formula becomes:

$$C = \frac{(B_{1S} + B_{1D}) - (B_{2S} + B_{2D})}{B_{1S} + B_{2D}}$$

where B_{1S} = specular brightness of background,

B_{1D} = diffuse brightness of background,

B_{2S} = specular brightness of object, and

B_{2D} = diffuse brightness of object.

If a task such as ordinary black ink, having a specular reflectance of 0.9% and a diffuse reflectance of 2.7%, is printed on mat white paper, having a specular reflectance of 0.3% and a diffuse reflectance of 77%, the contrast with diffuse illumination of 70 footcandles would be computed as follows:

$$C = \frac{(.77 - .027)70}{(.77)70} = .965 \text{ or } 96.5\%$$

This might be the diffuse illumination on the work plane coming from a window using venetian blinds as a control medium. If, on the other hand, the 70 foot-candles of illumination were produced by an overhead fluorescent fixture in which the reflection of the fluorescent tube could be seen if a mirror were placed in the position of the task, the contrast would be computed as follows, taking the brightness of the fluorescent tube as 1840 foot lamberts:

$$C = \frac{[(.003)(1840) + (.77)(70)] - [(.009)(1840) + (.027)(70)]}{(.003)(1840) + (.77)(70)}$$

$$= \frac{59.4 - 18.7}{59.4} = .685 \text{ or } 68.5\%$$

The resultant loss in contrast would be 28%. It would take approximately four times as much illumination to bring the task in the second example up to the relative visability level of the task in the first example.

Fortunately, the task is not always in the mirrored reflection angle. However, Finch (9), Chorlton and Davidson (8) and Blackwell (2) have shown that many tasks have great losses due to specular reflection, even when the task is not in the mirrored angle with the light fixture. Furthermore, when the task is pencil on white paper, the loss of contrast is even greater, owing to the high specular reflectance of the pencil and the indentation it produces on the paper.

The problem of reflected glare is far more complex than the simple example shown here. Using more complex calculation techniques and measured results, Finch (9) has shown the loss in contrast for ink on paper to be as high as 50% when the source of illumination varies from a light coming over the right shoulder to an incandescent lamp at the mirrored visual angle. When a fluorescent lamp in the same glare angle was substituted, he found a loss in contrast of 45%. When pencil on paper was substituted in the same conditions, the measured contrast changed from 43% to 9% and 11% respectively. With a similar task Chorlton and Davidson (8) found a contrast loss of 21.6% for direct illumination, 20.2% loss for general diffuse illumination, and 10.8% loss for luminous direct illumination. The illumination level in this experiment was 30 foot-candles provided by a normal lighting layout. The losses were compared to a lighting environment produced with an overhead baffle eliminating most of the brightness in the mirrored reflection angles.

It is apparent that illumination on the task coming from large angles of incidence greatly reduces the disability glare caused by reflected glare. It is also obvious that indirect lighting or luminous ceilings would also greatly reduce the disability glare caused by specular reflection. However, one must be careful not to create a direct disability glare when designing a lighting installation. One must also be careful of taking laboratory data and extrapolating it to actual environmental conditions that include many factors left out in the laboratory tests.

ECONOMY OF DAYLIGHTING

Probably the most interesting aspect of window design to the building owner is the economy of daylight utilization. I have described some of the types of economic cost models available for comparing alternate types of building components at the BRI Conference on Methods of Building Cost Analysis (10). O. F. Wenzler gave an economic analysis of integrated lighting at the same conference (27). From a lighting viewpoint alone, it is obvious from Wenzler's analysis that daylighting is economical. His study of the effects on the thermal environment points out that for equal levels of illumination there is less heat per foot-candle for daylighting than there is for electric lighting. Many people have experienced a blast of heat from windows with sun on them. Unfortunately, not all daylighting installations are properly designed. When a high amount of heat comes through a window, there is usually far more daylight than is necessary. If proper controls had been installed, the heat would have been reduced to a desirable level.

A common mistake in comparing the economy of daylight utilization with that of electric lighting is made by many air conditioning people. The person figuring the air conditioning load fails to realize that foot-candles of illumination obtained with daylighting produces less heat than equal foot-candles produced by electric light. The normal procedure is to assume a fixed electric lighting load and consider any daylighting as an additional heat load. This assumption is erroneous and does not recognize the advantages of daylight utilization.

OTHER FACTORS

There is very little information available on the acoustical transmission through various types of building materials. However, this is not an important factor in window design except in extremely noisy areas. In most environments background noise is desirable and actually makes the room seem quieter. Too little noise can be quite disagreeable. In normal areas a tightly closed window gives a satisfactory acoustical environment. Double glazing appears to give an even quieter environment than single glazing.

Some thought should also be given to safety. A window makes an excellent entrance for firemen and exit for escape from fire. Also, a window can be broken for ventilation, to avoid asphyxiation in a fire.

The window area should be properly designed and engineered to produce the most desirable effect at the lowest cost. It should not be just placed on a building for vision out, because people feel cooped up and unhappy without it. However, some economic value should be placed on the preference of windows to space without windows. Building progress has taken us out of the cave. Shall we now go back in?

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Design of Skylights

by Ben H. Evans, Texas A & M College

Abstract: Natural lighting is man's most preferred source of illumination, and the roof or ceiling is the most logical place for this light. Skylights can be used economically and effectively for high quality daylighting, without undue heat gain. The main design problem is brightness control, especially control of the brightness of the skylight materials. The surface of the skylight must be shielded or a high density material must be used in the dome, if it is viewable from below. Design procedures are outlined for lighting with skylights, and brightness values are presented for the first time for various skylight plastic dome materials.

THE ADVANTAGES AND DISADVANTAGES of skylights and the general range of information available for predetermining the characteristics of skylights are discussed from the architect's point of view.

MAN LOOKS TO NATURE

Man's development of his technical abilities has far exceeded his wildest dreams of only a few years ago. He can today pretty well control his environment. He can produce and control his own atmosphere, his surrounding temperatures, his sonic and esthetic environment -- his visual environment. He can produce all the air, sound, and light that his heart desires.

But man still looks to nature for the fulfillment of his greatest desires. He prefers natural breezes to air conditioning and natural light to electric light. Man's desire for the qualities of nature which he cannot entirely reproduce is always a pertinent factor in building design. Men feel a kinship to all living things and there is within them an intense desire to explore and understand all the facets of nature. For this reason, the lighting of our indoor environments will and should contain a significant amount of natural lighting.

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NATURAL LIGHT

Natural light has, of course, been the most important source of building illumination through history, until the Industrial Revolution. The influence of man's need for natural light shows all through recorded history. In the early days of development, man was completely dependent upon natural light. Early man always provided a small hole of some kind in his tent or hut to let in light and let out smoke. Even in Egypt, where there is an overabundance of light, early Egyptian architects took great care to provide interior natural light.

In the classic Pantheon church in Rome, lighting effects were produced by a 27 foot diameter hole in the crown of a monstrous 142 foot dome. This was then the largest dome in the world, covering approximately 2 million cubic feet. The space is most sufficiently and pleasingly lighted by the 27 foot "skylight." The dome opening (or eye) also has a symbolic meaning. The idea was that worship should relate to the heavens and to the "illumination" of mankind by God. So you see natural light has a spiritual quality also.

Artistically and mechanically, nothing could be better than leaving the "eye" of the dome open, but before the invention of glass, it was intolerably inconvenient whenever rain or snow fell. A change, therefore, was brought about in subsequent buildings with the use of four circular holes in the dome just above its springing. Thus, natural lighting devices were put into the vertical plane until glass came into use.

Moving still farther north, Gothic architecture came into being, again with natural lighting playing a big role in style and character. With the development of light structural elements and high arches, coupled with the extensive use of glass, the Gothic Cathedral was the epitome of naturally lighted buildings.

USE OF SKYLIGHTS

As the problems involved in designing for good natural lighting have become more familiar and better understood, more and more complicated control devices have been developed and are becoming the curse of practical, economic architecture. In revolt against this trend of architectural design, many architects across the world are going back to the roof for their light.

The roof or ceiling of a room is the most logical place for sources of general illumination. Skylights can and have been effectively used for lighting interiors for many centuries. However, it is only recently that skylights have been designed and prefabricated for easy, economical, and waterproof installations. Postwar economic stresses on school buildings and an enlighted demand for greater quantities of good, natural light have stimulated this development of skylights.

BRIGHTNESS CONTROL

Quite early , the problem of controlling the brightness of the skylight material arose as a significant factor. Clear materials were objectionable because they allowed direct view of the bright sky and because they allowed direct sunshine to enter. Thus, the translucent or "milky" skylight material was developed in order to diffuse the incoming light and eliminate the bright spots of sunshine.

The translucent materials, in turn, introduced another problem. When exposed to direct sunshine, the translucent materials were often excessively bright, again causing eyestrain. Continued demand for quality lighting conditions have brought about the use of very high density materials which do provide very low surface brightnesses even when exposed to direct sun. With such a low transmittance material, it is usually necessary however, to use very large skylights to provide sufficient light on the room task. The incoming light should be diffused as much as possible and spread over as large an area as possible.

To illustrate the advantage of this principle, consider the following example. Assume a two-foot square skylight with a translucent dome of "T" transmission factor. Assume conditions that provide a level of illumination below of 62 foot-candles. This produces a certain dome brightness. If, then, the skylight is enlarged to twice its original size and the transmission factor of the dome reduced to provide the same foot-candle level below of 62 foot-candles, the dome brightness, then, will be considerably less. The illumination level of 62 foot-candles is still provided, but the brightness of the ceiling dome is much less, since the same amount of incoming light has been spread over a larger area.

Skylight manufacturers are now providing numerous variations in skylight materials, allowing designers to select a material, or a combination of materials, that will produce almost any desired lighting condition. The prismatic glass-block is an example.

Architects and illuminating engineers have for many years sought a simple, accurate method for determining the natural lighting conditions of their buildings while they were still in the design stages. Several methods for predetermination have been developed.

Most mathematical illumination prediction systems are based on the lumen input method as described in the IES Lighting Handbook (1). The system is basically the same as that used for the design of electric light systems.

$$\text{TOTAL LUMENS} = \frac{\text{average foot-candles x lighted area}}{\text{interreflectance factor}}$$

Any given skylight, under a given condition, will produce a given number of lumens to the interior space of the building. The number of these lumens then available on any task area below is based on the size of this area, its distance from the skylights, the shape of the space, and the finish on the surface surrounding the space.

DESIGNING FOR SKYLIGHTS

The typical procedures for designing for lighting with skylights are:

1. Decide how much light is desirable for the task being performed. The IES Lighting Handbook (1) provides recommendations for most tasks, but these should be tempered by common sense.
2. Decide how much of the room area must be lighted by skylights. Adjacent areas may be lighted by windows or electric lighting. If the supplement is from windows, there are tables which provide an estimation of how much area can be lighted by the windows alone.
3. Determine the effects of the room geometry on the skylighting by finding the room index:

   $$\text{ROOM INDEX} = \frac{\text{room height x (room width + length)}}{\text{2 x room area}}$$

4. Using the room index, establish also the effects of the various room surfaces on the skylighting by finding the interreflectance factor. Tables are available which provide these interreflectance factors.
5. Calculate the total number of lumens required to produce the desired results:

   $$\text{TOTAL LUMENS} = \frac{\text{average foot-candles x lighted area}}{\text{2 x room area}}$$

6. After determining the number of skylights desired

   $$\left(\frac{\text{Total lumens required}}{\text{Number of skylights}} = \text{lumens/skylight}\right)$$

   and their spacing, select the size of skylight and the skylight material that will supply the required number of lumens. The particular skylight can be selected from a lumen table.

BRIGHTNESS VALUES FOR PLASTIC DOME MATERIALS

Unfortunately, not enough information is available on that most important factor, brightness. We need to know complete brightness values for various skylight plastic dome materials. Such values have been developed by the Texas Engineering Experiment Station and have not previously been made public (see Figure 1). The brightness of skylight materials is a very pertinent factor in designing for daylighting. It may be argued that skylights can be secured from the direct view of the people involved in performing a task below so that skylight brightness is not a problem and this may be right in some circumstances. However, there is a direct relationship between the transmission factor of an obscure glass or plastic, and the resulting surface brightness produced by a given light source.

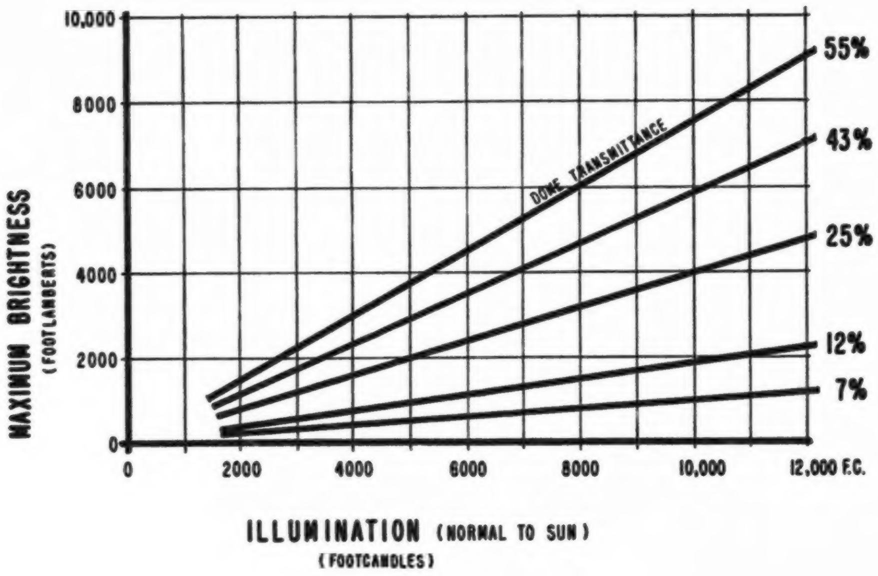

Figure 1 -- Plastic dome skylight brightness.

(I assume this true, also, for prismatic block.) These brightness curves are based on the maximum brightness values possible with the various materials. This involves viewing the skylight plastic dome materials from a point directly opposite the light source -- the sun. Thus, the design of a skylighting system should take into consideration the potential brightness of the source, just as do systems with electric lighting.

SKYLIGHTS AND HEAT

Skylights have long been criticized for the quantity of heat they transmit. The criticism is often valid, even if misunderstood. In very general terms, it may be said that light and heat are essentially the same thing, so that where there's light, heat will be there also -- almost in direct proportion. (This is the architect here. The scientists may criticize this simplification.)

It usually, then, comes as a surprise for people to learn that, per unit of light, skylights -- or daylight -- produce less heat than most equivalent electric lighting systems. The figures in Table 1 show how daylighting produces more lumens per watt than electric lighting of the more common varieties, and in terms of air conditioning needs, how daylighting requires less cooling per unit of light. This shows that skylights produce better than we often given them credit for.

Solar Heat Gains Through Domed Skylights by L. F. Schutrum and N. Ozisik indicates the quantities of heat that can be expected from various types of plastic domed skylights under various sky conditions (2).

TABLE 1 -- EFFICIENCY COMPARISON
OF SKYLIGHTS AND ELECTRIC LIGHTING

Source of Illumination	Light Output		Air Conditioning Load
	Lumens/ sq. ft.	Lumens/ watt	Tons/100,000 lumens
Daylight through acrylic plastic, high transmission	5,270	106	.27
Daylight through acrylic plastic, medium transmission	3,110	106	.27
Incandescent light	---	20	1.90
Fluorescent light	---	60	.63

COST COMPARISONS

Lastly, we must consider the costs for lighting systems whether they are electric or otherwise. Table 2 shows a typical comparative cost analysis for three different systems of lighting -- skylights only (in this case plastic dome skylights), fluorescent lights only, and skylights and fluorescent lights together.

In this analysis we consider all normal expenditures directly related to the various lighting systems. There is the first cost, uniform annual cost of recovering first cost, annual cost of insurance, annual costs for lamps, annual labor costs for cleaning and relamping, and the annual power cost. The summation then gives the total annual lighting cost, or the annual cost per foot-candle. Notice that daylighting is the least expensive method of lighting.

Of course, there are factors involved other than economics. There is the general atmosphere being created by the architect, which, in the final analysis, is the primary factor in all decisions.

SUMMARY

In conclusion, let me summarize briefly:

1. Skylights can be used economically and effectively for providing high quality lighting in architectural spaces.
2. Surface brightness, if viewable, must be kept to a reasonable minimum, either by shielding, or through the use of a low transmittance material in the skylight itself.
3. Skylights provide a good quantity of light without unreasonable quantities of heat as compared with other systems.
4. Skylights provide a means as economical as any for providing good quality daylighting.

TABLE 2 -- COMPARATIVE COSTS OF SKYLIGHTS, FLUORESCENT LIGHTS, AND THE TWO IN COMBINATION

Cost Consideration	Source of Illumination		
	Skylights[1]	Fluorescent Light Units[2]	Skylights and Fluorescent Units[3]
First cost of lighting installation (less lamps)	$480.00	$657.00	$881.00
Uniform annual cost of recovering first cost at 3% for an operating period of 25 years	27.56	37.75	50.59
Annual cost for insurance at 1.2% of first cost	5.76	7.89	10.57
Annual cost for lamps	---	8.72	1.33
Annual labor costs for cleaning and relamping	3.00	10.80	9.60
Annual power cost	---	59.24	9.05
Total annual lighting cost	$ 36.32	$124.40	$ 81.14
Annual cost per foot-candle	.74	2.43	1.62

[1] Six skylights, 36 x 36 in., 43% transmission with louver shade; average lighting level: 49 foot-candles.

[2] Eighteen fluorescent units, two 40-watt lamps, 45° louvers; average lighting level: 51 foot-candles.

[3] Six skylights and 11 fluorescent units; average lighting level: 50 foot-candles.

REFERENCES

1. Illuminating Engineering Society. Lighting Handbook (3rd ed.) New York: the Society, 1959.
2. Schutrum, L. F., and Ozisik, N. "Solar Heat Gains Through Domed Skylights," ASHRAE Journal, August 1961.

Design of Electric Illumination

by W. S. Fisher, General Electric Company

Abstract: The electric lighting system should be designed to provide all the illumination necessary or desirable for the working environment. Daylighting and electric lighting must be coordinated, using the same brightness criteria. It is important to select appropriate luminaries, based on some appropriate visual comfort assessment, and to install them for the desired distribution of general illumination. Heat gain from lighting must be considered and the visual and thermal aspects of building design can be coordinated through the Electrical Space Conditioning concept. Automatic lighting controls are not generally recommended. The electric lighting system should function continuously during the working day, with some variation in environmental lighting desirable for pleasantness.

WE ARE INTERESTED in electric lighting only as it makes its contribution to the total visual environment. If the visual environment is appropriate for the space, it must provide for the aspects of pleasantness and for the factors of quality and quantity in illumination.

PLEASANTNESS

The integration of physical factors into the total environment has a profound effect on the emotional responses, attitudes and performance of persons who must occupy the space. Some of these physical factors are form, color, texture, and pattern. Lighting makes contributions both to the appearance of the materials of the environment and of itself by virtue of its brightness pattern, color, and form. Lighting's contribution to an environment is unparalleled.

Pleasantness is discussed first since all too often the lighting approach is to cover quantity of illumination first and leave esthetics until the last. The intent is not to deemphasize any of the factors of pleasantness, quality, and quantity in illumination. They are all present in every environment, though the degree of importance attached to each may be different.

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QUALITY OF ILLUMINATION

Everything in a working environment has a potential effect on seeing -- and lighting affects everything in the space. Therefore, it is not enough to think only in terms of fixtures and layouts in providing for the visual needs of working eyes. A complete lighting specification must go much further than specifying the type of luminaire, how many of them, and in what pattern they should be installed. This brings the matter of lighting quality into the picture.

In every working environment where critical visual work is performed, a specification for quality in lighting should include:

1. Recommended reflectance values for all the room surfaces and work surfaces.
2. An assessment of direct view visual comfort for the luminaire which will be employed in the space. The Visual Comfort Index (VCI) is recommended as the most comprehensive comfort evaluation method currently available. The Scissors Curve, though somewhat inflexible, can also be helpful as a guide in selecting appropriate luminaires.
3. An assessment of veiling reflections and their importance. Most visual tasks undergo a contrast loss of 10-15%, or less, when illumination is provided by well-shielded lighting equipment. For many tasks, this is negligible. However, for some of the low contrast, specular visual tasks, it may be serious.

If veiling reflections appear to be a serious factor in a working area, one of the following suggestions may be helpful:

a. Lighting must be limited to luminous ceiling or luminous indirect luminaires.
b. The veiling effect of the reflection must be minimized by placing work locations in between and parallel to the rows of luminaires.
c. If task-viewing angles are of the order of 60° or greater, polarizing panels employed as shielding media for the lighting equipment can be helpful. However, if viewing angles are more commonly 10°, 25° or 40°, such panels may be no better (or possibly poorer) than many of the commonly used lighting materials.

QUANTITY OF ILLUMINATION

While quantity of illumination is deliberately discussed last, because of all too frequent overemphasis, it is of basic importance for these reasons:

1. To ensure that enough light is provided in terms of current knowledge, practicality, and economics so that people can efficiently perform their visual tasks.
2. To establish the heat gain from the lighting for evaluation in terms of the building's heating and cooling requirements.

3. To determine the desirable lamp type and luminaire for an economical investment in lighting equipment and a reasonable lighting pattern in terms of pleasantness.

RELATIONSHIP OF ELECTRIC LIGHT TO DAYLIGHT

The utilization of daylight for lighting visual tasks in working areas requires consideration of a great many factors. For example, its variability makes it undependable. Daylight can change from several thousands of foot-candles to a few tons of foot-candles within a relatively short period of time. In addition there are many outdoor visual conditions -- such as direct sunlight, cloud cover -- which are very uncomfortable if they intrude on one performing demanding visual work.

1. The electric lighting system should be designed to provide all the illumination felt to be necessary or desirable for the working environment. This is the only sensible approach to lighting design, since daylight is not always available. However, daylight is always a welcome supplement to an electric lighting system, because even if recommended levels of illumination are provided in working areas, they are by no means considered the maximum or optimum values.
2. Brightness criteria applied to electric lighting systems and visual environments should also be applied to daylighting. For example, the same brightness limitations should apply to a window wall as to the interior walls in a working area, and the same criteria should be used in evaluating the visual comfort of overhead skylights as are used with luminaires.

All glazing must be shielded -- both side and top -- so that the maximum brightness will be acceptably comfortable for the people in the space. If this is done satisfactorily, then the contribution of daylight will be small on overcast days.

To insure visual comfort with daylighting, blinds, shades, draperies, wide overhangs, louvers, low transmission glass, and similar devices should be designed and specified as an integral part of the building.

One aspect of coordination between electric lighting and daylighting which is beginning to receive attention is the visual transition from the inside of a building to the exterior. Increasing the electric illumination on the window side of the room makes the visual transition from inside to outside less abrupt. It also maintains a more uniform distribution of electric lighting across the room, since with typical symmetrical lighting layouts, illumination levels will fall off substantially below the average around the perimeter.

Another area where coordination between daylighting and electric lighting is nearly always overlooked is in the traffic pattern of buildings from exterior, to lobby, to elevator, to corridor, to office, or the reverse. While it is not necessary to provide daylight's highest levels of illumination indoors, steps in brightness should be planned that would insure transitions made with comfort and safety into or from a building. Here is an area where illumination levels measured on a plane 30 inches above the floor are meaningless. The brightness of the surfaces determines the adaptation and visual comfort of people. More use of building materials which can be lighted effectively, and lighting planned specifically for wall surfaces, will create the desired room brightness. Luminous walls are also very effective.

SELECTING APPROPRIATE LUMINAIRES

Anyone who has the responsibility for specifying or buying lighting equipment would do well to assure himself in advance that it will be acceptably comfortable to the majority of people who must work under it.

Comfort evaluation of luminaires is complex. It involves not only the average brightness of the luminaires themselves, but the area of lighting equipment disposed in the field of view, the size and proportions of the space, and the surrounding brightness. Much progress has been made in recent years in the knowledge of what brightness conditions people will accept as being comfortable or uncomfortable.

In addition, the matter of assessing the visual effect of a roomful of luminaires has been solved, using the Visual Comfort Index method. Computations are made from a seated location at the center of the rear of the room, assuming a horizontal line of sight toward the front of the room. Data are tabulated for different room sizes and expressed as a percentage of people who, on the average, would be comfortable under the specified conditions at the center, rear location. Any other location in the room will be better than the spot from which the computations are made, as there will be fewer luminaires and less brightness in the field of view for the horizontal line of sight.

We would not encourage hairline distinctions between luminaires for which VCI data is available. Luminaires 4% or 5% apart are probably comparable. However, there are a surprising number of luminaires for which the VCI may be less than 50%. This may be partly responsible for the large number of poor quality lighting installations. The application of an appropriate comfort evaluation system as an additional check will help to upgrade lighting quality.

INSTALLING LUMINAIRES

In working areas, it is usually desirable to distribute the general illumination uniformly. Some guides to luminaire location and spacing follow:

1. Where rows of fluorescent luminaires are parallel to the walls, the distance between luminaires and walls should not exceed one-half the distance between the rows of luminaires.

applications where they have been employed. Though a good case could be made for the use of automatic lighting control on the basis of lower operating cost over a period of time, in actual practice the theoretical advantages are outweighed by two major disadvantages:

1. Maintenance. The second or third time the controls require attention, they are usually cut out of the circuit. Manual switching is then employed, if anyone takes the trouble to adjust the lighting.
2. Desirability of keeping all the lighting operating. Any working environment is nicer and more pleasant with all the lights on. The room appears to be in better balance with all the electric lighting on, and the additional daylight from windows does not hurt a thing as long as it is comfortable.

USE OF VARIABLE ILLUMINATION

Variable illumination for many building interiors has exciting possibilities. This area of lighting is expected to have a rapid growth in view of the newer equipment recently available. As you may know, the 30-watt and 40-watt rapid start fluorescent lamps with the proper circuiting can be dimmed very nicely. However, even with incandescent lamps, dimming applications are on the increase.

The components necessary to dim fluorescent lamps include:

1. A dimming ballast, one for each lamp. Recently a wide-range dimming ballast has been made available which will provide a dimming range of greater than 300 to 1, even with the simplified dimming circuits, compared with the previous typical 10 to 1 range.
2. A source of variable voltage. This can be supplied by a variable autotransformer, mounted in an electrical wall box, in a closet, or in a remote location; and by silicon-controlled rectifier (SCR) dimmers which are physically small and offer the promise of considerably lower cost.

The kinds of spaces to which dimming is applicable include:

1. Auditoriums. Levels of illumination in auditoriums vary with the visual activity. For example, before a stage presentation begins, there are casual visual activities. During the stage presentation a relatively low level of illumination is desirable. If the auditorium is used for exhibits, conferences, bridge parties, study halls, etc., even higher levels of illumination will be necessary. Some of these requirements may be handled by employing different lighting systems and switching them individually. However, dimming may enable a single lighting system to fulfill several different functional requirements.
2. Private offices and conference rooms. When the activity requires critical visual work, one level of illumination may be desirable. When the activity is principally conversation, a somewhat lower level may be desirable. Switching can provide

2. The ends of continuous rows of fluorescent luminaires should preferably be within 6 in. to 1 ft of the wall and in no case more than 2 ft from the wall.
3. Where desks are located along the wall, the distance between the row of luminaires next to the walls should preferably be 2-1/2 ft and in no case should it exceed one-third the spacing between rows of luminaires.
4. Maximum spacing to mounting height ratios for equipment should not be exceeded. We have all seen lighting installations which could be described as marginal at best -- where all the rules and guides for illumination quality have been taken to the maximum allowable limits. The quality of lighting is appreciably better if we can stay well within the extremes of the suggested ranges, especially for spacing relationships. The closer the rows of luminaires are spaced, the fewer troublesome shadows and reflections occur.

LIGHTING HEAT

In many of the commercial buildings of today, the electric lighting systems provide a significant heat gain. This heat gain may equal from 50% to more than 100% of a building's heat losses for the design condition. This aspect of lighting is too often overlooked.

In this area lies a great opportunity for improving system design and building economics. This concept is becoming known as Electrical Space Conditioning (ESC). In its simplest form, the term implies the coordination of visual and thermal aspects of building design. However, the ESC concept could also include cleanliness of the atmosphere, bacteria content, presence or absence of negative ions, and to some extent odor control.

The most important aspect of ESC is the lighting-temperature relationship. Much of this lighting heat can be controlled. The significance of ESC is that it will not be practical to design the lighting as something separate and apart from everything else in the building. The work of the electrical and mechanical engineers will require greater coordination than ever before, with fresh approaches and ingenuity on their part. The prospects for new equipment designs from manufacturers are encouraging.

The best proof of the opportunities which this concept affords are in the increasing examples where resourceful architects, engineers, and users have worked out successful solutions that capitalize on the thermal properties of lighting systems. These and others like them are the forerunners of many more to come, where lighting makes an increasingly important contribution to the environments in which we live and work.

AUTOMATIC LIGHTING CONTROLS

In my experience, automatic lighting controls have not worked well and have seldom been used for long in the relatively few interior applications where they have been employed. Though a good case could be made for the use of automatic lighting control on the basis of lower operating cost over a period of time, in actual practice the theoretical advantages are outweighed by two major disadvantages:

1. Maintenance. The second or third time the controls require attention, they are usually cut out of the circuit. Manual switching is then employed, if anyone takes the trouble to adjust the lighting.
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some flexibility in obtaining different illumination levels, but it is not nearly as satisfactory as a smooth dimming unit which avoids great variations in the overall brightness pattern.

3. Wall lighting. Special circuits for lighting the walls in any area are appropriate and may be enhanced by dimming controls. For example, wall lighting on dimmers may be desirable in critical visual work areas. Variable lighting for walls is desirable to change the brightness pattern and shift the emphasis and mood, as for example in a restaurant, as a means of changing the atmosphere from that appropriate for noontime lunches to that conducive to leisurely evening dining.
4. General offices. It is interesting to speculate on the effect of variable illumination levels as it may affect the attitude and performances of people in work areas. There has been some rationalization that it might be good to increase illumination levels in work areas during the middle and late afternoon periods as a means of stimulating productivity. Another approach suggests varying illumination levels on a slow cycle through the working day, possibly to achieve effects similar to daylight as cloud conditions may change lighting levels and brightness patterns. While the ideas are intriguing, they must certainly be called untested.

It would be better to provide the best general lighting system that we know how and allow it to function continuously through the working day. However, there could be shifts in the brightness and color pattern of the walls or ceilings by adding or changing accents at different times during the day. However, it would not appear to be conducive to concentration to the task at hand if there were sudden abrupt shifts of any kind during working periods. Any changes that were incorporated during such a time would preferably be on a slow cycle dimmer, say, 30 minutes or longer.

SOURCES OF DESIGN INFORMATION

A great deal of literature is available on lighting design. Publications of the Illuminating Engineering Society are detailed and authoritative, and the General Electric Company has several technical publications on lighting design.

Open Forum Discussion

Moderator: Orville L. Pierson, Rohm & Haas Company

Panel Members: Messrs. Evans, Fisher, and Griffith

Mr. Griffith: Mr. Fisher, you said that the same brightness limitations that are applied to electric lighting should be applied to windows. However, the criteria you described are not based on large area sources and cannot be applied to windows. Can they be applied to skylights? Also, you suggested that all windows should have controls on them. Are there not places for uncontrolled daylight?

Mr. Fisher: The smaller skylights take on about the same size and proportion as lighting fixtures. Some of our design guides for electric lighting systems could be applied there.

Louvers should not be applied indiscriminately in every place, but louvers do give lower brightness than most of the highly diffusing lighting materials employed today. An unlighted ceiling, or a wall which may be reflected at the mirror angle, will have lower brightness than the lighting fixture, and we can have the very low brightness provided by the louvers.

Joseph A. Anderle, Levelor Lorentzen, Inc.: Please comment on the efficiency of venetian blinds for the viewpoint of controlling light, particularly in providing for projection of visual aids?

Mr. Fisher: Venetian blinds can provide very good brightness control. Slats tilted upward will still allow ground light. Some diffusely reflected light will go up to the ceiling, bounce across, and perhaps distribute the daylight better. Venetian blinds will, of course, block out the outside brightnesses which can be quite disturbing through clear glass. With regard to visual aids, venetian blinds can still be helpful. A little light through the blinds is desirable because it provides some illumination in the room so that people can take notes or so that they can move about without accident.

Mr. Griffith: Mr. Evans, did you use the average brightness, or did you use the maximum brightness in your paper?

Mr. Evans: My figures are based strictly on absolutely maximum pinsource brightness. They could not be used on the scissor curve.

Mr. Pierson: This is one marked difference between daylighting and electric lighting. Where in electric lighting we speak of an average brightness from a given viewing angle, in daylighting we talk generally of the maximum brightness as seen through a material.

Mr. Evans: We found it extremely difficult to measure skylight surface brightnesses over a wide range of conditions with good consistency. We still need more work in this area. It is difficult to pinpoint exactly what the brightness ratio and the illumination levels should be.

Joseph A. Rorick, IBM Corporation: To what extent is daylighting being utilized today for industrial applications, and as an environmental factor, what are the experiences with respect to daylighting and cloudy days?

Mr. Griffith: I assume you are talking about indoor industrial application. Daylighting is used considerably. I don't know the number of square feet of glass sold, but I know it is relatively high. In nearly all cases daylighting is supplementary. In this country, the illuminating engineer thinks of himself as an electric lighting engineer and of daylight as a supplementary light source. In the rest of the world, daylighting is thought of as the major source and electric lighting is supplementary. Many lighting consultants do not know both aspects of lighting, and, consequently, only deal with one phase. I would never design a lighting installation without good electric lighting.

R. P. G. Pennington, Board of Education, Toronto, Canada: Is 98.5% contrast a desirable feature of classroom illumination? Has this ever been related to pupil eyestrain over prolonged periods of time? What percentage contrast should be our optimum?

Mr. Griffith: You could have such a high brightness that it would be unbearable. We do not have to worry about this because in this country we are designing to relatively low levels of illumination, However, there would be a maximum level where you might want to cut your contrast down purely to eliminate direct glare.

Mr. Fisher: From the standpoint of the task, you would like to have 100% contrast on every task that you look at, have the detail of the task reflect no light, and have the surroundings reflect 100% of the light diffusely. This would give you the very best visual conditions. If you have a white background for many tasks, or relatively light colored tasks, then about 400, 500, or 600 foot-candles represent about as much light as you can put on a task and still maintain good comfort. If you ever tried to read a letter on the beach at Miami, you know the brightness can be very uncomfortable when white paper is in full sunshine. There are optimum levels of illumination beyond which you should not go, and these are keyed to task brightness.

Garry Allen, Dow Chemical Company: How important a factor is winter heat loss through skylights? Is it serious enough to limit their use?

Mr. Evans: Heat loss is significant in the winter. There is a very simple device to overcome this -- the double skylight which provides two panes of plastic with an airspace between to provide some insulation. This has a minimum of effect on the lighting coming through it.

Mr. Jaros: Even with double glass in cold climates, have you not found that aluminum sash and frames in operable or fixed windows cause serious condensation, and even frosting, when 30% to 40% relative humidity is maintained in the building?

Mr. Griffith: I suspect that this would be a problem. I think it could be overcome in fixed windows by design of the device holding the pane or the glass in, but I'm not sure about the operable windows.

Mr. Pierson: Some of our experience with tinted glazing has indicated that there is a psychological reaction against use of this material because building occupants complain of a feeling of gloom or depression. Would you care to comment?

Mr. Fisher: I certainly agree that there is this reaction, due principally to the great variation in daylight and outside brightnesses. In a building located in Southern California where they have a great deal of sunshine, it may be more appropriate. The heavily tinted glazing should always be used with an overhang, so that you do not get direct sunlight on it. Direct sunlight on this very low transmission glass raises the glass temperature to the point that it radiates half the heat inside and half outside. We have had to move work positions away from this source of radiant energy where direct sunlight falls on it.

Window Design in Europe: A Review of Recent Research

By Thomas A. Markus, Pilkington Brothers, Ltd.

Abstract: This paper reviews recent technical research in Europe on design of windows. Specific areas discussed are daylight quantity prediction and measurement, daylight quality, supplementary artificial lighting, legislative control of daylight, heat transfer (thermal transmittance, heat balance calculations, shading and cooling, condensation), sound insulation, fire resistance, meteorology and windows, and window economics. Studies mentioned are briefly described and are cited in the 76 references.

THIS CONFERENCE IS ESSENTIALLY about the properties of the building shell as a protective and filtering skin. Non load-bearing light walls go some way toward resembling the skins of "endo-skeleton" creatures such as ourselves compared with the heavy structural predecessors which were both skin and skeleton -- the architectural "exo-skeleton" equivalent of lobsters. They would, however, have to develop much further, in particular in combination with thermal services, to equal the efficiency of blood, nervous, glandular, evaporation, shivering, and goose-pimple functions. Economics, comfort standards, and modern construction demand a rapid development toward this goal.

Windows play a special part in this development because of their dominant role in determining room climate. They combine the visual, thermal, and acoustic elements of environment; and therefore we need to know more about the relationship of these. Since environmental services can cost up to one-third of the initial cost of a building, we need to know how best to invest available funds: Are visual requirements dependent on room temperature? Does noise affect glare discomfort? To what degree are we influenced by what we think is happening? Is discomfort additive?

Beyond these functions, windows are also links between two worlds. In early civilization, holes in structures were sometimes

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symbols for the entering of a spiritual force at a certain moment in a ritual. Today, the aperture may serve as a link with sky, nature, city, or people -- all elements having their own symbolic, cultural, or social meaning. This "metaphysical" function of the window deserves more study than it has so far received.

DAYLIGHT QUANTITY PREDICTION

Daylight design in Europe differs fundamentally from American practice in that it is not based on absolute illumination levels but on a fixed ratio known as the daylight factor, which has been fully defined by the Commission Internationale de l'Eclairage. This is the ratio of the amount of light available at a point in a room to the total light from an unobstructed hemisphere of sky simultaneously available outside, expressed as a percentage. On the assumption that the sky has a constant luminance distribution, this gives a figure which is constant, irrespective of changes in sky illumination.

For example, a 10% daylight factor on a dull day with a total external illumination of 500 lumens per square foot is equivalent to 50 lumens per square foot, whereas on a brighter day with a doubling of external illumination it is equivalent to 100 lumens per square foot.

By analysis of meteorological data, it is possible to select for any purpose a daylight factor which will give the required illumination over the required period of time. In practice, owing to the position of the sun, there is some variation of sky luminance with orientation and the luminance distribution also varies with altitude. It has, however, been found that on days of densely overcast sky, which are the most critical from the daylight point of view, the brightness from horizon to zenith varies in the ratio of 1:3. This sky luminance distribution has been internationally accepted and defined by the equation: $\frac{B}{B_Z} = \frac{1 + 2 \sin\theta}{3}$ where B is the sky luminance at an altitude θ° above the horizon and B_Z is the zenith luminance. It is frequently referred to as the Moon and Spencer sky (47). It has also been found by measurement that, in London for example, the total illumination drops to below 500 lumens per square foot on only about 10% of normal working hours throughout the year and therefore in Britain 500 lumens per square foot is frequently taken to be the minimum sky condition to be used for the determination of daylight factors. However, more refined values are needed which take latitude, orientation, micro-climate (e.g., the presence of pollution), and working hours into account.

The total daylight reaching a point in a room arrives from three sources: directly from the sky, by reflection from external surfaces, and by reflection from internal room surfaces. These components of daylight are referred to in the standard literature as the sky component, the external reflected component, and the internal reflected component.

Provided the luminance and luminance distribution of a patch of sky or an external obstruction seen by a point through a window are known or assumed, the question of determining the amount of light the point receives from outside becomes one of solid geometry. It is necessary to integrate the flux reaching the point. In passing through glass, account has to be taken of the varying angles of incidence to determine the amount lost by reflection and absorption.

Many techniques for solving this problem of solid geometry have been devised, primarily aimed at determining the Sky Factor, i.e., the illumination from a uniform sky through an unglazed opening. Most have adaptations or alternate versions.

One of the earliest methods, and probably still the most widely used in Britain, is the set of Building Research Station Protractors for giving direct readings of sky factor or sky component under five basic conditions: vertical, horizontal, 30° sloping, and 60° sloping glazed apertures, and unglazed apertures (25). For each of these, a protractor has been designed to be used on the section of the building, the scale being arranged to take into account both the cosine effect and, where it applies, the loss due to glass. Each deals with an aperture infinitely long on plan and has an auxiliary protractor to give corrections to take into account the limited length of apertures. No protractors for a non-uniform (CIE) sky are available, but by means of conversion factors depending on the mean altitude of the visible sky, the readings can be corrected.

Another British method, used where the external obstructions are complex in outline, is the Waldram diagram (72, 73, 74, 75). This is, in fact, a projection of half the sky vault (Figure 1). The azimuth scale is uniformly spaced while the altitude scale is contracted towards the horizon and towards the zenith to take into account two effects: first, with increasing altitude, equal areas of sky produce greater illumination on a horizontal plane; and second, with increasing altitude, the total area of visible sky is reduced. The vertical scale can also be designed to take into account a non-uniform (CIE) sky, as well as glass losses. On this family of diagrams, so-called "droop-lines" are drawn which represent horizontals, making it a relatively simple matter to plot the outlines of a window and of any external obstruction. The ratio of the area of a remaining patch of sky to the total area of the diagram (which represents half the hemisphere of sky) represents twice the sky factor or sky component.

Some techniques for determining the sky component give an unrealistic picture of the sky vault and external obstructions or they are not easily used with traditional building projection, i.e., plan, section, and elevation. A technique designed to overcome these difficulties is described in the paper by Pleijel. The sky vault is represented by a stereographic projection of a hemisphere on which can also be shown the outline of a window and any external obstruction and hence the patch of sky seen by a point. By dividing the area of the sky into small units of equal mean luminance, the total

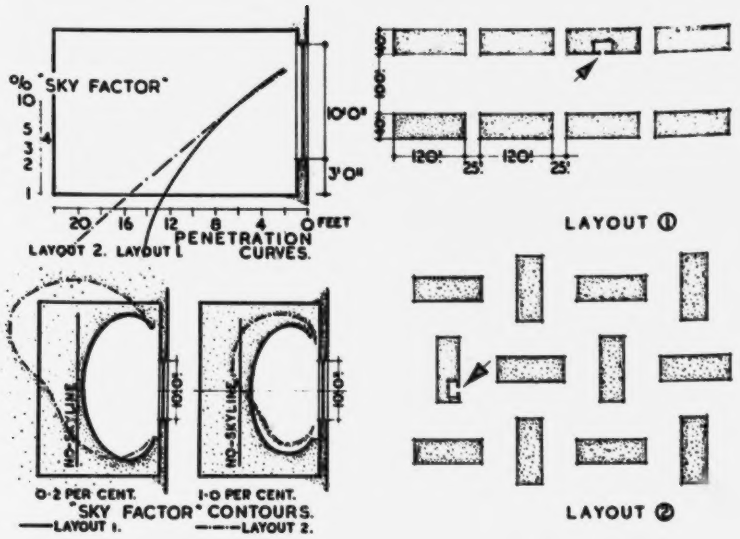
% "SKY FACTOR"
10
5
3
2
1
20
16
12
8
4
0 FEET
PENETRATION CURVES.
LAYOUT 2.
LAYOUT 1.
10'0"
3'0"
40'
100'
40'
120'
25'
120'
25'
LAYOUT ①
NO-SKYLINE
NO-SKYLINE
10'0"
10'0"
0·2 PER CENT.
1·0 PER CENT.
"SKY FACTOR" CONTOURS.
LAYOUT 1.
LAYOUT 2.
LAYOUT ②

Figure 1A -- Two alternative building slab layouts, with plans and sections showing sky factors.

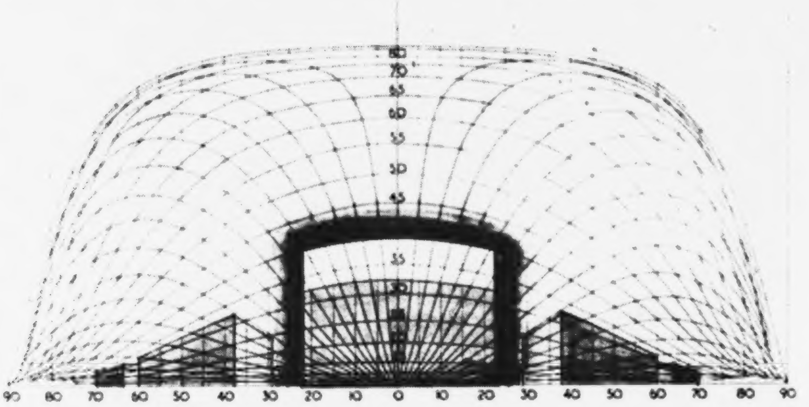
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Figure 1B -- Waldram diagram for determining sky component for layout 1, above.

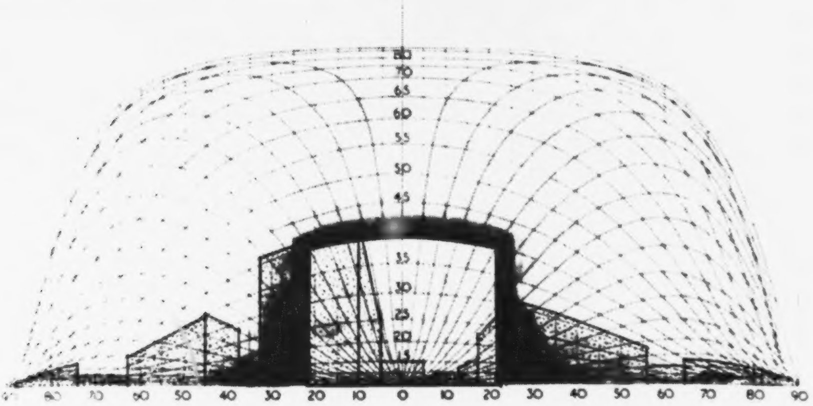
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Figure 1C -- Waldram diagram for determining sky component for layout 2, above. SOURCE: Petherbridge, P. "The Computation and Measurement of Sky and Daylight Factors, "Building Research Congress, 1951. Crown copyright; reproduced by permission of the Controller, H. M. Stationery Office.

illumination can be obtained by counting the number of units in a given patch of sky.

An additional advantage is the ease with which sun-path and radiation diagrams can be plotted on the same projection, relating shading as well as heat transfer problems to daylight calculation by means of a single technique. The possibility of photographing complex obstructions on the surface of a parabolic mirror, giving a photograph on the same projection, further enhances its usefulness.

A similar projection has been used by Tonne of Stuttgart (63), whose Horizontoscope enables obstructions, as well as sun-path diagrams, to be observed on a reflective but translucent plastic paraboloid.

In France techniques have been developed by Cadiergues (10) for determining the illumination from rectangular windows on a horizontal plane where the window dimension and the distance of the point from the window are known. Other techniques have been developed by Dourgnon, Chauvel, and Fleury (13, 22) where again the angular geometry of the window in relationship to the point is diagrammed. Curves are available for CIE and uniform skies, for both glazed and unglazed openings. Other graphical techniques have been developed by Daniljuk (15), where the projected area of the sky hemisphere seen by a point is represented on plan and section projections; by Kittler (33) in Czechoslovakia, who uses a series of interrelated nomograms taking into account not only geometry but also the reflectance of the room surfaces and hence the internal reflected component; and by Vollmer (69), who uses a projection similar to the Waldram diagram.

The external reflected component is usually also calculated on a geometrical basis similar to that used for obtaining the sky component, making some assumptions about the illumination falling on the surface and its reflectance. In the absence of more accurate data, a generalized assumption is made; for instance, in Britain a luminance equivalent to 1/10 of the luminance of the sky obstructed is frequently used.

To obtain the internal reflected component by calculation it is necessary to determine the degree to which a room acts as a light integrator. This will depend on its geometry, the area of the window, and the reflectance of the various surfaces. It is also necessary to know the relative strength of the light flux. Most workers have split this into two parts: the flux entering from above the horizontal and therefore arriving first at the floor, and the flux entering from below the horizontal and therefore arriving first at the ceiling. Reference has already been made to Kittler's technique, which includes an allowance for interreflected daylight. Calculations made by Hannauer (28) and by Spencer and Stakutis (60) have also solved this problem theoretically, the latter by applying integration in a perfectly diffusing window in a side wall.

Other techniques have been based on the theory of the integrating sphere, such as those of Arndt (2), Dresler (23), and Pleijel (54, 55). Techniques which assume an equal-intensity flux falling on all surfaces have not proved sufficiently accurate; it is necessary to split the flux at least into the two major components (that arriving from above and that from below the horizontal). Hopkinson, Longmore, and Petherbridge of the British Building Research Station have produced an empirical formula for the internal reflected component (31) based on this division and expressed it by means of nomograms.

These daylight factor calculations can be carried out as a simple routine. Once mastered, they not only give a quantitative answer but enable design alternatives to be systematically studied.

DAYLIGHT QUANTITY MEASUREMENT

There is often a gap between predicted and achieved daylight factors because of inadequate knowledge of the effect of deposition of dirt on glass, translucent and other types of window blinds and shades, furnishings and condition of room surfaces, internal obstructions, light-directing and diffusing glazing materials including glass blocks, and reflectance of the external ground, balconies, and other projections.

A number of workers have constructed artificial skies in which both the illumination levels and the sky luminance distribution can be controlled and under which scale models of rooms of buildings can be placed for full daylight factor surveys. Two main types of sky have been used in Europe: a flat, box sky in which lighting is placed above a diffusing ceiling and the walls are mirrors to give an infinite horizon; and a hemispherical or large curved sky, lit from below and lighting the model by reflected light. Both types have been constructed for CIE and uniform skies, and examples exist in Britain, Sweden, Denmark, and Czechoslovakia (34). Many of the most valuable studies on the effect of interreflection from room surfaces, street and building reflections, and spacing of roof lights in roof-lit factories, have been carried out on such models. They have also been used for work on permanent supplementary artificial lighting of interiors and on glare. Many architects make regular use of models to judge lighting and color schemes at the design stage.

The measurement of daylight factors in buildings involves the measurement of total outdoor illumination and illumination at the point in question, if possible simultaneously. A variety of instruments have been designed to do this, such as those at the Building Research Station (39, 52) and that at Pilkington Brothers Limited (35, 65). In the latter, the two measurements are made simultaneously, and the ratio of the two currents is measured.

Whatever technique of prediction is used, it is possible to draw daylight factor contours both on the plan and on the section of any type of building, which show the variation of daylight quantity within a room. These contours are the final result needed by the designer to investigate alternate solutions.

SUPPLEMENTARY ARTIFICIAL LIGHTING

The actual value of daylight factor has generally been based on recommended illumination levels in Codes and Standards translated into daylight factors via a sky illumination representing a lower limit, say 500 lumens per square foot or 5,000 lux. With recent increases in the recommended levels of illumination, the translation of recommended levels to daylight factors by this process produces daylight factors which could not be met in many cases without unduly limiting the depth of rooms or extending their height.

With this problem in mind, the British Building Research Station has worked for some years on the development of a technique for mixing daylight and artificial light so that daylight still plays a dominant part in the lighting of the room but the parts of the room away from the window receive adequate illumination for the task, thus maintaining the balance between artificial and natural light without creating a sense of gloom (30). Simply "topping up" the daylight with artificial light at the back of the room to give the required illumination levels does not solve the problem.

Even on a dull day, an observer's judgment of the relative brightness of the sky seen through the window and the brightness of his immediate environment at the back of the room may give rise to complaints of gloom. It has therefore been necessary to design for illumination levels higher than the "topping up" procedure would indicate. It may seem paradoxical, but the higher the brightness of the outdoor sky, the higher the levels of the permanent supplementary artificial lighting have to be.

Permanent supplementary lighting is recommended in the form of a recessed lay-light flush with the ceiling, with good diffusing properties giving illumination levels of the order of 20 to 50 lumens per square foot at the back of the room. Such a level has been found by subjective experiments to satisfy relative brightness judgments within a wide range of sky brightnesses. This technique is now being applied in technical colleges, hospitals, offices, and schools. The supplementary lighting is separate and distinct from the normal night artificial lighting (which may be designed to lower levels), the changeover taking place toward late afternoon or evening. This technique is clearly distinct from that of the totally artificially lit environment, with windows provided as "vision strips" but performing no useful lighting function, and it is likely to make a considerable impact on the future of building and lighting design in Europe. The British Illuminating Engineering Society Lighting Code accepts it as the basis of the daylight recommendations, but it has been criticized for giving too little guidance on daylight design.

DAYLIGHT QUALITY

Since World War II, much more emphasis has been placed in Europe on quality aspects of lighting and particularly on glare. As a result of extensive glare studies at the Building Research Station (53) and in America and Europe, it is known that the glare sensation varies directly as a function of the source luminance and size and varies inversely as a function of the background luminance. Workers have reached different conclusions on the functions to assign to these elements. Those used in Britain and published in the British IES Code are given in the simplified formula:

$$G = \frac{B_s^{1.6} \cdot w^{0.8}}{B_b} \qquad \frac{1}{p^{1.6}}$$

where G = glare constant
B_s = source luminance (ft.-L)
w = solid angle subtended by source at eye (steradians)
B_b = background luminance (ft.-L)
p = position index

While the full implication as applied to windows is not yet known, some work has been carried out and indicates the general validity of the relationship (29) if the value of B_b is based on average luminance of the whole field, including the source which now affects visual adaptation. The relationship is of great importance to window design, for it shows that the effect of a change in size of window is less significant than a change in its luminance (or the luminance of what is seen through it). If this is true, it means that reduction of window luminance by means of tinted glasses for transparent windows and good diffusers for translucent windows is of considerable importance. Studies are now being carried out to determine daylight distribution through translucent glasses and the effect of semi-diffusing or light-directing glasses on the luminance of walls and ceilings and hence on the glare sensation.

LEGISLATIVE CONTROL OF DAYLIGHT

There are examples in Europe of the regulation of daylight by means of codes, standards, and administrative means. In Great Britain, for instance, for all teaching areas in schools a minimum daylight factor of 2% has to be provided, and this regulation has influenced the whole planning and design of post-war British schools. In Germany, a National Standard (20) exists which lays down minimum recommended daylight factors varying from 1% to 10% according to the type of building and task. For school classrooms, for example, it is 2%, for living-rooms 1% to penetrate at least half of the depth of the room, and for school laboratories 5%.

Studies have been made of the relationship of town planning to daylighting. In Britain the Permissible Height Indicators (46) have been used for some years by central and local authorities to test the spacing of building blocks. They are designed to test the adequacy of daylight penetration to windows within a comprehensive development scheme and the adequacy of daylight penetration to the boundaries of a scheme where property ownership changes. The indicators have given architects and planners a new freedom to break away from corridor streets in high density development.

A thorough study has been made by Büning (9) of daylight penetration in rooms on various floors of blocks of flats and the effect of height, spacing between blocks, and heights of each floor. He takes into account heating and lighting as well as constructional costs. Much work remains to be done, particularly in relationship to window glare, the mixture of daylight and artificial light, and the economics of daylight.

HEAT TRANSFER

Physical and Physiological Effects

One of the primary functions of the window is to act as a selective energy filter. To a large extent, the total heat content is determined by the flow of heat through windows. Windows are critical in determining the short-term response of thermal conditions in rooms to outside climatic changes and solar radiation levels. This energy flow not only affects physical conditions but also comfort.

Thermal Transmittance

In Northern Europe, with its relatively severe winter climate and a summer climate that has traditionally been regarded as being sufficiently mild not to necessitate artificial cooling, most effort has gone into the determination and prediction of winter heat losses. In Britain particularly, great emphasis has been placed on air temperature differences between the outside and the inside and the resultant convection/conduction heat flow.

Full-scale tests on north-facing room-size structures with fixed internal air temperatures have been carried out for some years at the Building Research Station on walls and roofs including both vertical and sloping glazing (4, 24, 45, 58). The heat loss has been defined in terms of air temperature difference only, by means of the thermal transmittance (U) value. Naturally, variations in solar radiation with orientation, season, time of day and cloud conditions affect the net heat transfer and result in such anomalies as negative U values - i.e., a net heat gain when the temperature in the controlled room is higher than the temperature outside. These measurements have yielded useful results on the physical properties of wall and roof materials and structures.

Radiation has been accounted for on a mean basis over the heating season by using different external surface resistances for differing orientations. U values calculated in this way appear in the standard heating engineering guide (32) and probably give reasonably accurate results for energy requirements over the whole of a heating season. However, the error introduced due to the inclusion of solar radiation is multiplied by temperature difference and hence becomes largest in the calculations for the coldest periods.

U values tell one little of the short-term effects of solar radiation which may be significant both for the design of heating plant and for seasonal energy requirements. For example, the standard U value for a south-facing window exposed to normal wind is only 79% that of a similar window on a north exposure. Using these values for calculations of peak load, which may well occur at night when there is no solar radiation and the heat transfer is the same on both orientations, would result in under-design on one exposure or over-design on the other or both. The indiscriminate use of these mean U values accounts for much under- and over-estimation of heating losses where there are large windows. Some designers have even tried to use them to solve heat-gain problems.

Heat Balance Calculations

What is needed is to calculate the heat flow due to temperature difference and the heat flow due to solar radiation (including long-wave radiation exchange between the glass and the sky, ground, and room surfaces) and to express the result as an algebraic sum. The net result may be a heat balance, heat gain, or heat loss and could be computed for mean air temperature and radiation levels over any desired period or for peak conditions - in winter at night or on dull, cold days with the minimum of solar radiation, in summer on warm days with maximum solar radiation. Such a system would also yield different results for buildings heated during the day-time only and those heated for 24 hours. A committee of the British Standards Institution is debating this whole subject of heat transfer calculation through building structures. It is to be hoped that a general proposal of this kind will be the outcome, both for opaque materials and windows.

Once solar radiation is properly accounted for in the window heat transfer calculation, problems of solid geometry arise. For diffuse sky radiation it is necessary to determine the patch of sky seen by a window (as distinct from a point in the room in daylight calculations), and for direct solar radiation the position of the sun at any moment in the year has to be determined. Once again the techniques developed by Pleijel, which are treated in his paper, admirably solve these geometrical and energy problems. By means of sky radiation diagrams, drawn to stereographic projection on which sun-path diagrams and shading masks can be superimposed, the calculation becomes relatively easy. Much of this theoretical work has been carefully checked by meteorological measurements and by controlled experiments where the net heat flow through windows was measured and correlated to climatic and room conditions.

Tonne of Stuttgart, with Normann and Schmidt (64), has carried out similar calculations and has drawn up the heat balance for a window over the season, which clearly indicates the period of net heat gain and net heat loss and the times at which there is a heat balance. Using techniques based on Pleijel's and Tonne's work, it is possible to present directly the differences between north and south elevations, for example, on a given site or the differences between a single and double glazed window, and to integrate the areas under the various curves to obtain the differences in heating or cooling energy requirements (Figure 2).

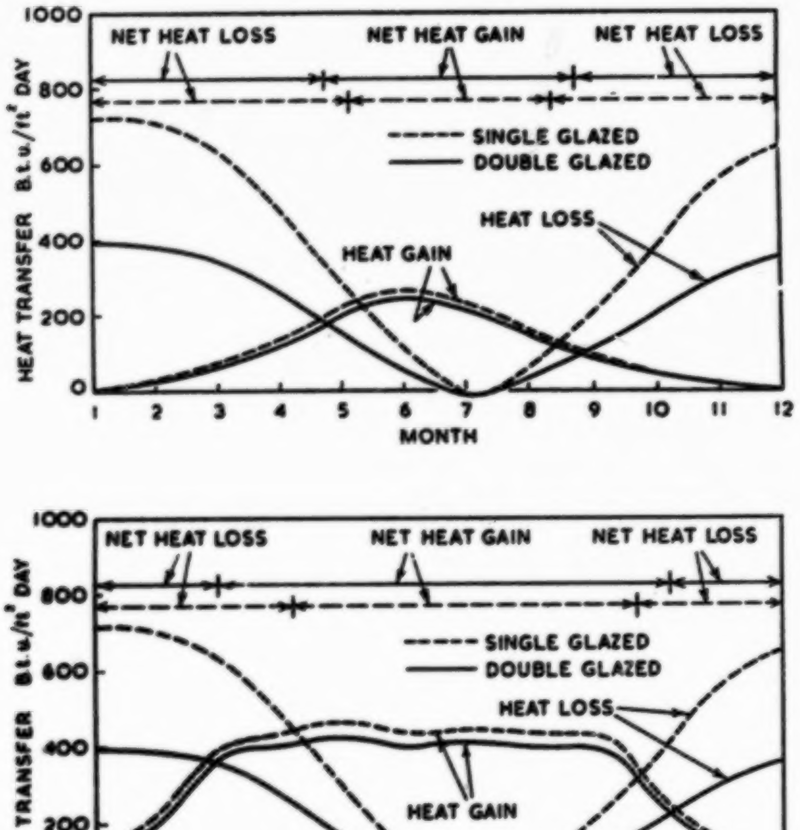

Figure 2 -- Heat balance of single and double glazed windows. Top: north-facing; bottom: south-facing. SOURCE: Pleijel, G. "The Heat Balance of a Window," Byggmästaren, No. 1, 1959. Adaptation: Markus, T. A. "Heat Transfer Through Windows - Windows and Insulation, Part 2," Insulation, November 1961.

Shading and Cooling

The arrival of buildings with large windows has quickly made designers in Nothern Europe, and even in Britain, aware of the fact that we do have a summer heat gain problem and that summer air-conditioning is frequently necessary. However, much less attention has been paid to this aspect in Europe than in the United States.

In France full-scale room experiments have been made on net heat transfer through various types of windows, including heat-absorbing glasses and blinds (12). The room temperatures are allowed to rise in accordance with outside air temperature and radiation changes. Immediately behind the windows, a series of grey, veil-like curtains are suspended and the walls of the rooms are painted white; the curtains absorb all transmitted solar radiation and quickly release it to the room, where it is registered as a rise in air temperature.

The French Heating, Ventilation and Air-conditioning Guide (18) treats the problem of heat gain through windows in some detail, including a mathematical solution for the net heat transfer through glass, taking into account direct transmission, reflection, absorption and reradiation to both sides, and convection losses to both sides. Useful graphical data is also included on various glasses and double glazing systems which divides the total energy incident on the glass into the three portions of reflected, absorbed, and transmitted, and shows changes in their relative magnitude with angle of incidence. The French glass company of Saint-Gobain has also studied these heat gain and shading problems and produced valuable data (14).

An object lesson in the difficulty of predicting heat gain through windows, even with elaborate design and architectural techniques, is the UNESCO Building in Paris. External horizontal concrete louvers, carefully designed to shield the sun at known times of the year, a grey glass solar shield similarly designed, and internal white curtains were used, yet during the summer of 1959 the heat gain in one wing was so large that office personnel refused to carry out work. The reason for this was the assumption that shading would be needed when the mean temperature in Paris rose above 70° F., but the uncomfortable heat gains took place at lower mean air temperatures when the sun could partially penetrate the shading devices. A final attempt to improve conditions has been made by fixing external venetian blinds on the façades concerned. While they now cope with the heat gain problem, there are all the problems of cleaning, maintenance, and repair as well as rather astounding sound effects as the wind travels along the blinds on the curved façade.

The experience of the UNESCO Building and similar glazed office buildings in Europe has shown the need for practical instruments or graphical methods for the solution of shading problems. While a few architects have simple heliodons on which shading around building blocks can easily be studied by models, regular use of sun-path diagrams and shadow angle protractors is rare. In fact, few standard publications containing these are available in Europe. In Britain the 1959 edition of the Institution of Heating and Ventilating Engineers' Guide (32) included the first diagram and tables dealing with sun angles. Sun-path diagrams for a variety of latitudes, together with shadow angle protractors, have been available in some of the Commonwealth and tropical countries and something more about them is in Pleijel's paper.

Condensation

A thermal problem associated with windows is the avoidance of condensation and the preservation of through-vision. While a double glazing system is the normally accepted solution, the amount of fundamental research dealing with this problem is limited. One Swedish study by Nycander (48) investigates the relationship between air space dimension between two panes of a double window and the degree of ventilation to the outside air as determined by the width of the ventilating slit at the bottom and the incidence of condensation. Apart from occasions of a sudden drop in outside temperature, it has been found that a slit 1mm wide at the bottom will prevent condensation for air-space dimensions up to 10 in. The question of condensation in ventilated air spaces and the loss of insulation due to ventilation (primarily for roof structures) has been thoroughly investigated at the British Building Research Station (57).

The question of air-infiltration and leakage through a variety of windows has been investigated in Norway (41, 76), Sweden (49), Germany (11) and Holland (67).

Codes and Standards

While a variety of codes of practice and standards exist in Europe dealing with heat transfer through building materials, limited attention has been paid to questions relating to windows. Exceptions are the Austrian Standard on Thermal Insulation and the German Standard on Regulations for Calculating Heat Loss from Building Structures (19), both of which specify values to be used in window heat loss calculations.

SOUND INSULATION

Sound insulation research has been carried out in Britain, Germany, Denmark, and Holland (7, 8, 26, 66). Experimental data show the all-important effect of adequate closure and the absence of air gaps, the importance of mass (weight) of glass and of adequate air space dimension in double glazing, the significance of sound absorbent lining in double glazing, methods of edge mounting, and other constructional details. The theoretical loss of insulation in thin barriers such as glass due to resonance at lower frequencies in both single and double glazing and coincidence effects at higher frequencies have been successfully measured (26). Some highly efficient double windows with insulation values of 50dB have recently been made.

Three general points should be mentioned:

1. Designers are now becoming aware that masking sound from street noise entering through windows can be useful in preserving privacy between one room and another. Where the windows are double, lightweight prefabricated partitions previously adequate for privacy may be inadequate without the masking sound. This emphasizes the necessity for considering noise from all sources.

2. It is also becoming realized that the sheer, smooth curtain wall façade creates reverberant sound fields in city streets. Glass set well back behind balconies, fins, louvers, and the other external breaks will reduce this effect and, where the sound source is directional, may keep some of the incident energy off the glass.

3. The linking action of the window between people and outer reality, while primarily visual, may also be aural. Limited aural awareness of traffic, people, weather (for instance, wind and rain) may for some people be a valuable feature.

FIRE RESISTANCE

Most fire research stations in Europe have at one time or another carried out tests on the fire resistance of various glasses and glass blocks (3, 27, 38). Although wired glass and glass block panels resist fire more than one hour under standard conditions, fire rules and regulations in many countries limit window and curtain walling areas and periods of fire resistance of glazing materials severely. In Britain the requirement for a fire-resistant wall between window heads and window sills can be traced back to fire regulations made after the Great Fire of London at the end of the 17th century. It is only recently that tests at the British Fire Research Station (17) and elsewhere have shown that such a fire-resistant wall makes little difference to the speed with which fire spreads within a building from one floor to the next.

With regard to window areas in outside walls and curtain walling, the regulations are coming into line with modern constructional technique without sacrificing safety. One system proposed (37) is to determine window areas from a triple sliding scale, taking into account the distance of a building from the boundary or adjacent property, the fire resistance requirements of the wall, and the window area. Such systems are designed to guard against the spread of fire from one building to another by means of radiation through the windows rather than to prevent the spread of fire within one building. The fire resistance requirements relating to windows must be considered together with problems of heat transfer and daylighting in relationship to general building layout and planning.

METEOROLOGY AND WINDOWS

No matter how refined techniques of daylight or heat transfer prediction become, the results will only be as accurate as the meteorological data used. While meteorological records are available all over Europe, only recently has the importance of micro-climate become accepted. It is known that within a city or a small area, large variations in temperature, wind speed, humidity and atmospheric pollution can take place -- that a new building alters the micro-climate immediately around itself. Two organizations are studying these problems: the Mixed Commission of Building Climatology of CIB (International Council for Building Research Studies and Documentation) and the International Society of Bioclimatology and Biometeorology. There is a lack of data on solar radiation on vertical surfaces for various orientations. Similarly, daylighting data recorded on a statistical frequency basis are few and often do not separate sunlight from skylight or determine the variations of sky illumination with orientation.

One of the most comprehensive studies of natural radiation is being made at the Belgian Observatory at Uccle under the direction of Dogniaux (21).[1] Here continuous records of diffuse, direct, and total solar radiation and of daylight have been made for a number of years, and their correlation with cloudiness has been established. Sky luminance distribution measurements are also made, and the results have been expressed on a statistical frequency basis. At Kew Observatory, and at other stations in a network linked to Kew, normal incidence direct radiation has been measured for many years, as well as total and diffuse sky radiation on a horizontal surface (61). Measurements of total daylighting including sunlight on a horizontal plane are also available, the earliest being made at the National Physical Laboratory before World War II (16) and expressed on a frequency basis. These measurements are often used in Britain as the basis for daylight design.

Extensive radiation measurements have been made in the Scandinavian countries (56). Radiation measurements are also available in Germany from Upper Bavaria (Holzkirchen), Karlsruhe, and Potsdam (68). Measurements of daylighting have also been made at Utrecht in Holland (51), divided into total and sky illumination, the latter obtained by shielding the sun.

Detailed measurements of wind pressures on high buildings, humidities near and around buildings, rainfall, and atmospheric pollution in rural and industrial zones are also in progress.

All this scientific work is invaluable once it is integrated into engineering calculations which are sufficiently refined to use the data. It may be that the tabulation of design data awaits the time when computers are regularly employed for building engineering calculations.

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[1] Reference 21 is a résumé of many valuable papers on radiation and illumination by Dogniaux et al. published by the Royal Meteorological Institute of Belgium.

WINDOW ECONOMICS

Architects and building owners are using cost planning and analysis as a design tool.

The cost discussion frequently centers around the question of windows or no windows or the amount of windows and the number of rooms to be lighted by daylight. In such calculations, the capital cost of window construction has to be weighed against capital cost of alternative materials, and the operating costs of heating, lighting, and maintenance must be compared. Any change in window construction such as double glazing will affect heating costs - both capital and operating - and, less obviously, the lighting costs. Cost of cleaning and maintenance, including that of blinds where they are provided, must also be taken into account.

In the thermal calculations, it is important to include physiological factors as well as the basic room air temperature. A person working near a large single-glazed office window will need higher room temperatures in winter than one near a double-glazed window.

There will be cases where calculations show a saving with the reduction or total omission of windows, particularly where heating costs are high and lighting costs are low. It is these cases which should remind the designer of the metaphysical function of the window. By means of cost planning techniques, he and his clients can see how much they are paying for qualities which cannot be economically assessed and can judge whether the cost is worthwhile. Cost planning is therefore not only a tool for finding the cheapest alternative but a way of deciding how much the intangible aspects of environment cost.

Already mentioned is Büning's work in Germany where different space/height relationships between blocks of flats are related to window areas and final costs. In Sweden investigations have related capital costs of different window types to heating, lighting, and maintenance (5, 36, 62). They show that an increase in window size always costs less than an increase in the number of windows to obtain the same total daylight area. They are investigating relative costs of different ways of sub-dividing a window, the effect of air leakage, and the effect of shape and number of panes. The relative economics of double and triple windows has also been investigated in Sweden (1), and it has been shown what climatic conditions are necessary before an economic gain results. A similar study in Norway shows how critically the margin between a net gain or loss is determined by fuel costs and interest rates on capital (40). Similar economic studies have been made in Germany (6, 59, 70, 71) and in Britain (43, 44). One by Manning at the University of Liverpool (42) investigated the economics of daylight with reference to roof lighting in single-story factories.

More important is the general acceptance of the cost planning and analysis techniques. When these become used as every-day tools, decisions on window design can be expected to become more rational. Meanwhile, more data is needed on summer heat gain problems, the availability of daylight, and maintenance costs.

CONCLUSION

Window design is a fertile field for all building science. There are complex physical problems, and there is much for the building physiologist and psychologist to learn. The economist and meteorologist are both drawn out of their customary fields into human environment. The manufacturer is aiming for a refined, self-regulating organ. The architect must combine technical solutions and relate them to indoor and outdoor space to satisfy deeply rooted desires. We are in the presence of one of the "arche-types" of architecture.

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Swedish Practices in Window Design

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Abstract: To understand window design in Sweden, it is necessary to know the climate and the standard type of window. Swedish methods of daylight prediction are diagrams and protractors (especially space-angle-projection diagrams, component cards, screen cards, and the new daylight discs), model measurements, and tables and graphs. Prediction of solar radiation is by means of solar charts, radiation cards, globoscope photographs, model studies, and tables and graphs. Recent Swedish investigations on glass and shading devices and on heat balance of windows are described. Many Swedish studies are cited.

THE WINDOW IS A SPECIAL DESIGN PROBLEM, which must be solved with respect to the climate. Since the variations and combinations of the climatic elements are unlimited, the solution will be different for every part of the world. To understand window design in Sweden, it is first necessary to know something about the climate there.

CLIMATE IN SWEDEN

From the Gulf Stream, heat comes to Sweden with the west winds. Low pressures from the west cause rapid changes between sunshine and rain. Sometimes a high pressure causes long periods of sunshine. On the other hand, in the winter we may not see the sun at all for months.

The low pressures always have a moving front between cold and dry air from the north and warm and humid air from the south. The air rapidly changes from cold and dry with a clear sky and sunshine to warm and humid with a cloudy sky, rain and snow. The temperature can drop 10°C (18° F) and rise again the day after. The normal mean temperature in the north is -12° C (10° F) in January. For long

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periods, however, the temperature can drop to -20°C and -30°C (-4° F and -22° F). In the south the mean temperature is about at the freezing point in January. During the summer the normal mean temperature is rather uniform over the whole country: in July it is +15°C (59° F) in the north and +18°c (65° F) in the south.

In April, when snow covers the north, flowers are growing in the south. Very seldom are temperatures up to 80° F.

The heating season is rather long -- in the north, ten months and in the south, seven months. Fuel consumption, however, is twice as much in the north as in the south. Since 80% of the fuel for heating is imported, houses are generally very well insulated. Double glazed windows are standard and in many houses one finds triple glass. Windows are always well weatherstripped.

Until quite recently, there was no need for cooling houses. Solar heat penetration through curtain walls and the large windows in the new office buildings, however, causes overheating. Many of the new buildings with glass façades have therefore been provided with air conditioning, including the possibility of cooling the ventilating air, but dwellings do not need any cooling.

Humidity is very low in winter, with a water vapor pressure of 1-3 mm Hg (1/16 - 1/8 in.). The relative humidity of the air inside is only about 35% in winter and there is no trouble with condensation, especially since the window curtain is often placed between the panes.

Solar radiation and daylight in Sweden have a different character from that of countries at more southerly degrees of latitude. The country lies between 56° N. and 68° N. latitude, the same as Alaska. The midnight sun is a well-known tourist attraction. The sun's path in the sky is rather low. In summer the maximum altitude at noon is about 45° in the north and about 58° in the south. The sun rises in the summer about 3 a.m. The sunset is about 9 p.m. in northwest. At midsummer the daylight never fades, in the north being about 100 foot-candles at midnight. In contrast to the long solar time during the summer, the sun shines only a few hours in winter, which is a long time of depressing darkness.

People in Sweden like sun and fresh air. Therefore, living rooms and balconies face west. Houses are often built with bay windows to catch even the winter sun from the south. The windows are usually not large enough for the rooms to get hot from the sun. The common shading devices seem sufficient. In the summer the windows frequently remain open.

Bedrooms often face east. Good shading is needed against the morning sun. The shading must be opaque and also keep out heat from the sun.

Because of the low water vapor pressure in the air the solar radiation is rather strong, especially in spring when the temperature is low. The maximum radiation on vertical façades then is about 800 kcal/m^2/hr(300 Btu/ft^2/hr) when the altitude of the sun is 30° over the horizon. Through the large windows in curtain walls, solar heat can cause a very high temperature inside. In the summer, windows to the southeast and southwest get the most sunshine. Even in Sweden cooling of houses with extensive glazing is now needed -- or an effective shading device against the heat from the sun. This is a very real problem.

The long dark winters in Sweden, especially in the north, cause problems with daylight and artificial light. The difference between daylight duration in winter and in summer is much greater than in more southerly countries. Immigrants from southern Europe cannot stand the winter darkness in the north. They get a serious depression called "Lapp-illness." Supplementing daylight with a strong electric light during the winter is therefore necessary. Unfortunately, the supply of water for hydro-electric plants is least in winter and much electricity goes to industry.

There is snow cover in northern Sweden during seven months of the year. In many places the frost never leaves the ground in summer. The snow is a good heat insulator and a good reflector of light and heat radiation. The light from the sky is therefore supplemented by the reflection from the snow. When spring comes, the reflection from the snow can be very strong and troublesome.

The clarity of the sky in the north is equal during the whole year, with a mean value of about 35%. In the south the difference between winter and summer is more marked. The summer value is about 45% and the winter value about 25%.

WINDOW DESIGN IN SWEDEN

In Sweden, standard windows are recommended by the Swedish National Commission on Standards (45) and represent about 80% of the windows made (Figure 1).

The standard windows are made of wood. They are casement windows (there are no sash windows in Sweden), with double glazing in two sets of coupled, side-hung sashes. The distance between the panes is 2 inches, because in Sweden the protection against the sun is put between the panes. The windows are carefully weatherstripped between the inner sash and the frame. This sash is pressed against the frame with an espagnolette bolt to get good air tightness. Between the two sashes there is a 1 mm slit, connecting the air space between the panes with the outside air. This is insignificant for insulation, but avoids condensation (6).

If triple glazing is desired, a hermetically sealed double glass on the inside is recommended.

DAYLIGHT PREDICTION

In Europe daylight factors under an overcast sky of the Commission Internationale de l'Eclairage (CIE) type are used (see Markus' paper, page 119). From the daylight factors, the absolute illumination values are obtained, with aid of curves or tables, for the

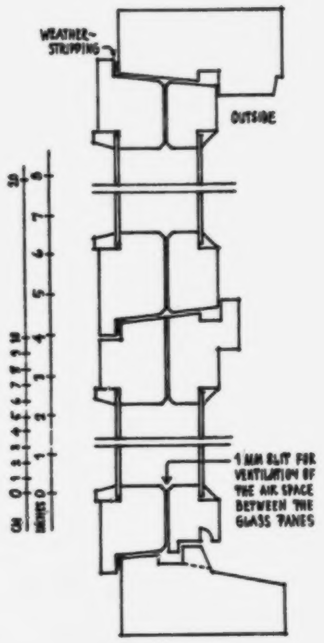
WEATHER-STRIPPING
OUTSIDE
1 MM SLIT FOR VENTILATION OF THE AIR SPACE BETWEEN THE GLASS PANES
CM
INCHES

Figure 1 -- Standard window in Sweden is wood casement window with double glazing in two sets of coupled, side-hung sashes. The distance between panes is 2 inches for putting in sun protection. Note weatherstripping and the 1 mm slit for ventilation.

diffuse illumination during the year. Mean figures of the illumination on a horizontal plane have been calculated for all latitudes in Sweden (11, 29).

For the prediction of daylight factors, the three principal methods are calculation with diagrams or protractors, model measurements, and tables or graphs.

Calculation with Diagrams or Protractors

The basic diagram is a space-angle-projection of the sky. From this principle, different diagrams and protractors have been developed. The first were made in 1930, based on a sky with uniform luminance distribution and modified for the transmission of window glass. They have been in use until 1955, when the CIE sky was recommended. A method for prediction of the internal reflected component of the daylight factor, based on the integrating sphere, was also developed but it has proved to be too complicated for practical use (7, 12, 22, 30).

In 1947 a type of calculation diagram was published, based on the method of perspective drawing (14). The picture plane was divided into equal square areas, each marked with its sky factor value. Therefore the diagrams were called value-diagrams. This type of diagram has not been much used.

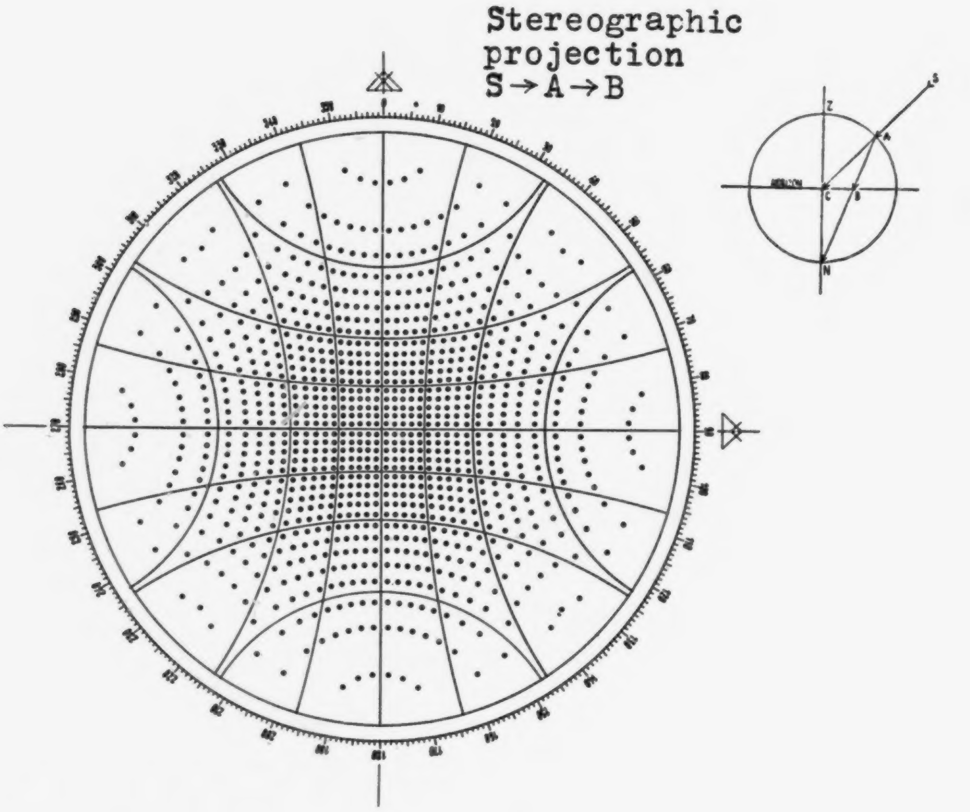

Figure 2 -- Component card. Stereographic projection of the sky on a horizontal plane. Every point is equal to a sky factor of 0.1%.

Another type of calculation diagram is the component cards, developed in 1954 (29), which can be used for calculation of the sky radiation factor and the sky illumination factor. There are two component cards, one for horizontal and one for vertical surfaces. They give the sky vault in stereographic projection (Figure 2). Every point in the diagrams represents a sky factor of 0.1%. Windows can be projected on the component cards by means of a screen card (Figure 3). The number of points covered by the projected figure gives the sky factor of the window. If the vertical and horizontal component are known, the sky factor of a tilted surface can be calculated with a simple formula. These component cards have mostly been used for calculation of the radiation from the sky (40).

Later another type of the space-angle-projection diagram was made, called the daylight disc. The projection of the sky is divided into 10,000 small equal areas, according to a method devised by Daniljuk, each corresponding to a sky factor of 0.01%. This diagram has recently been modified for the CIE sky luminance distribution and also for transmission of light through window glass (Figure 4). When the disc is used as a space-angle diagram, the window is projected on the diagram and the number of small areas covered by the

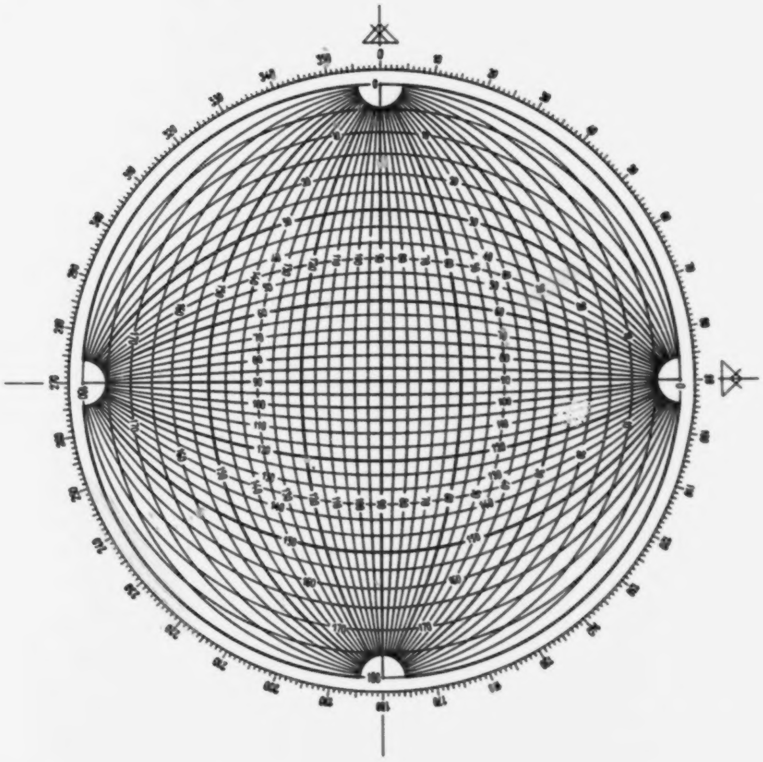

Figure 3 -- Screen card. This card contains the stereographic projection of two sets of lines parallel to the x-axis and the y-axis respectively (e.g., roof ridges). The angles of inclination of planes through the lines and the axis are indicated.

projection figure is counted, which gives the sky component of the daylight factor. When the disc is used as a protractor, the sky component of square windows can be determined by multiplying two numbers read off the diagram. Both techniques give a very precise sky component. This daylight disc method has not previously been published. It is still being worked on under a grant from the Swedish National Council for Building Research.

Model Measurement

Daylight studies in model rooms began in 1932 when influence of the wall color on the daylight in rooms was measured with a photocell in a scale model. These studies were made with the natural sky and were reported to the CIE (3). In 1940-42 daylight studies under an artificial sky were started. With photocells, corrected for the incidence error, measurements were made in models of rooms facing streets and courts. The sky was a flat one. The results of the measurements were published (9, 10, 17, 18, 21) and have been widely used.

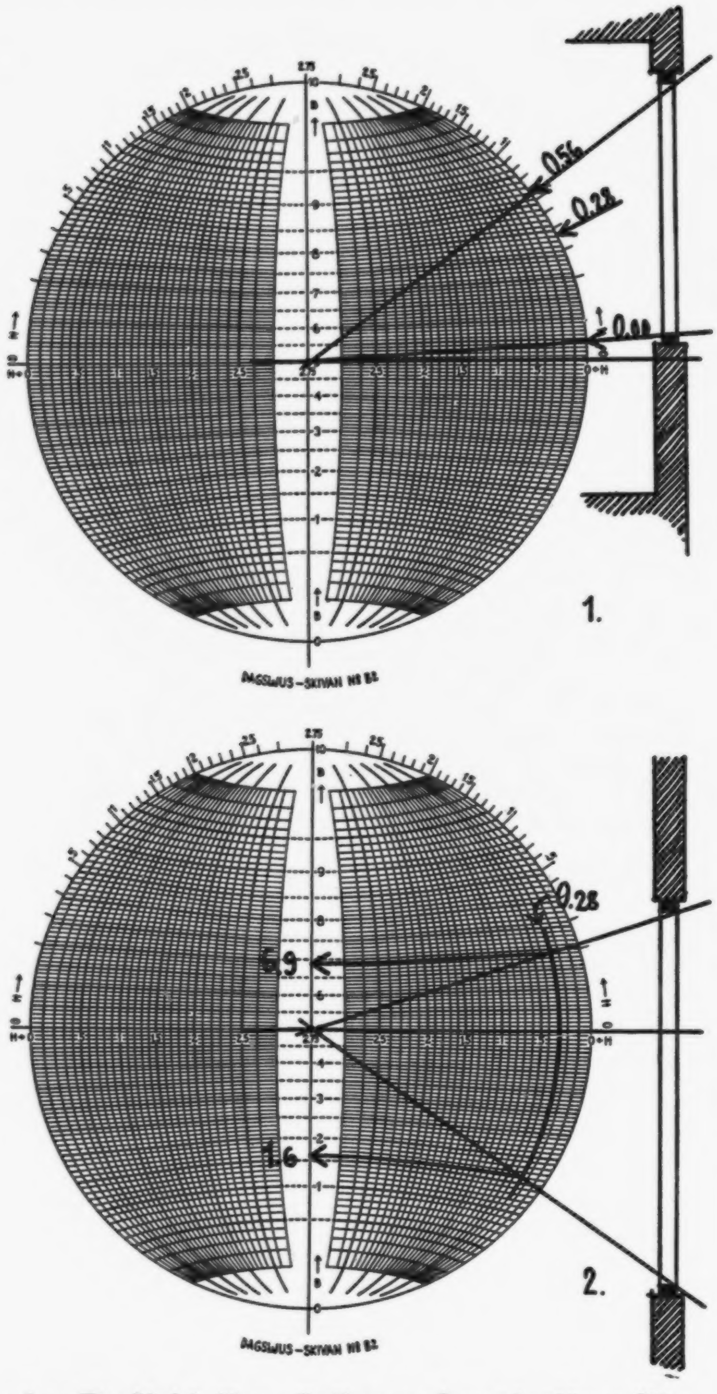
0.56
0.28
0.00
1.
DAGSLJUS-SKIVAN NR 82
0.28
6.9
1.6
2.
DAGSLJUS-SKIVAN NR 82

Figure 4 -- Daylight disc. Orthogonal projection of the sky on the horizontal plane, modified for the CIE sky and double glass. Each small square is equal to a sky component of 0.01%. For example: Stage 1 -- Two numbers are read off the circular H-scale, 0.56 and 0.00. Their mean value is 0.28; Stage 2 -- Two numbers are read off the B-scale, 6.9 and 1.6; Stage 3 -- Then the sky component is D = (0.56-0.00)(6.9-1.6) = 2.97%

Many model studies were also carried out in open air under the natural sky (13, 17, 26). In 1949 an artificial sky was erected at the Royal Institute of Technology. At first it was given a uniform luminance distribution, but this has been changed in accordance with the CIE standard overcast sky. Some 100 model studies have been made under this sky (4, 30).

The models are carefully built to different scales, from 1 in. to the foot for small rooms to 1/8 in. to the foot for large rooms. The reflected daylight depends on the reflection factors of the model room surfaces, which must be the same as in the real rooms. If there are obstructions to the daylight outside the room, these must be included in the model. The models may be made flexible with respect to color, window dimensions, etc. With aid of systematic experiments, tables and graphs can be drawn up of the influence on daylight of wall color, obstructions outside, façade reflection. Students at the Royal Institute sometimes take their examination under the artificial sky.

Tables and Graphs

Results of studies of a model with rooms facing streets and courts were published in the form of complete tables of daylight factors (18). Diagrams were then constructed from which the necessary window dimensions in different external and internal situations could be read quite easily. The Swedish National Council for Building Research also published these diagrams (23).

Graphs for window design in central urban areas, derived from these model measurements, were published by the CIE for the Congress at Stockholm in 1951 (20).

PREDICTION OF SOLAR RADIATION

Three types of solar studies are carried out in Sweden. First is study of the time of sunshine, which has a great psychological influence on man, especially in Sweden where there is not much sunshine in winter. Second is study of solar heat radiation, which has an influence on heating economy but can be very troublesome. Study of solar heat radiation will be intensified now because of the curtain walls and large windows in modern buildings. Third is study of solar illumination, which sometimes is good but sometimes must be excluded because of glare. Solar illumination studies have not advanced very far but there is a growing interest in protection devices against excess solar radiation.

For prediction of solar radiation different methods are solar charts plus auxiliary diagrams, radiation cards, globoscope photographs, model studies, and tables and graphs.

Solar Charts

The first solar position charts for calculation of solar radiation intensity and duration were made in 1936. The solar position in the

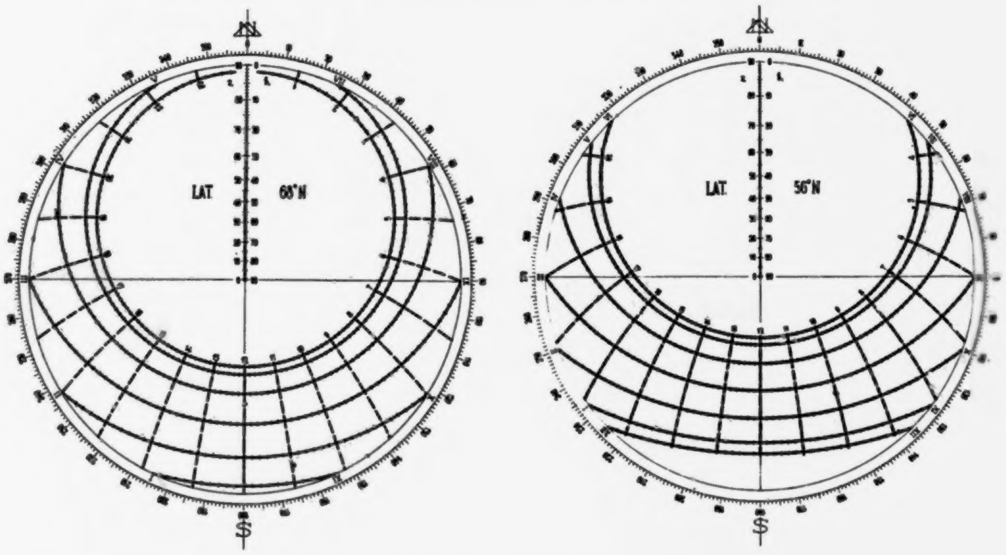

Figure 5 -- Solar charts for northern and southern Sweden. Left: Solar chart for the most northern part of Sweden at 68°N. Latitude, north of the polar circle. The sun never sets at the summer solstice and the curve for the winter solstice does not occur in the chart. Right: Solar chart for the most southern part of Sweden at 56°N. Latitude.

sky as seen from a point was then projected on a vertical cylinder, which was unwrapped. The solar charts were combined with a screen card for plotting of surrounding obstructions. A pinhole camera was also constructed for taking screen photographs of the whole area in one picture (8, 44). These diagrams and the camera have not been used very much.

In 1945 new solar position charts were constructed. They were of the radial type, which was much better for town planning studies. They were constructed for every second degree of latitude (56° - 68° N.) in Sweden (11, 16, 29), and also for studies at some other latitudes (19, 40). See Figure 5.

The solar charts are mainly for determining the duration of solar radiation. They are very useful for planning of sunbreaks, overhangs, and other shading devices and also for determining the shading effect of mountains, neighboring houses, trees, and bushes. For plotting of screen figures there is an auxiliary diagram, called a screen card (mentioned above). For rapid determination of angles of incidence of the radiation, a special incidence card can be used. The heat gain of a window can be rapidly calculated with this card in combination with a diagram of the intensity of the sun radiation at right angle and curve of the heat transmission of window glass.

Usually heat radiation is calculated with special equations. A method developed in 1954 uses the projections of the solar radiation vector on the three main directions north-south (x-axis), east-west (y-axis), and vertical (z-axis). These vectors can be tabulated and used in a simple formula for calculation of the radiation on any surface, vertical or tilting. The solar chart is then used only for determining the duration of the radiation.

The illumination from sun and sky is also dealt with in reference 29 and the ultraviolet radiation in references 28 and 29.

Radiation Cards

The calculation of daily totals can be facilitated by dividing the solar paths in the solar charts in successively accumulated radiation. Such cards have been drawn up for 60° N. Latitude (Figure 6). There are three cards, one for each of the main directions. The screen figure is laid directly on the cards and the substituting vectors are directly read off the solar paths. They are then combined in a simple formula. In that manner the daily totals of radiation on any surface, vertical or tilting, can be directly calculated.

Globoscope Photographs

The globoscope (Figure 7) was constructed in 1947 in connection with the radial solar charts (24, 25, 27, 29). It consists of a paraboloidal mirror with vertical axis of revolution, which is photographed from above through a lens. The camera can be replaced by the eye for direct observation of the picture in the mirror. When making a print, there can be put on the photographic paper a transparency of a solar chart, a component card, or a radiation card, which appears as a negative. Then the radiation duration, the sky radiation, or the solar radiation vectors can be read directly off the photographs.

Model Studies

Model studies in Sweden are carried out with aid of a small sundial, so that studies can be made in sunshine, which gives quite ideal conditions and parallel light. Indoors, sun light through a large window can be used. A spotlight or drawing lamp (15, 16) can be substituted for the sun.

The method is clear from Figure 8. The small sundial (3 x 3 x 3/4 in.) is placed on the model in horizontal position with respect to the horizontal plane of the model. Then the model is turned and tilted so that the shadow of the pin in the middle of the sundial points to the time of the day and the time of the year for the actual shadow to be studied.

Sundials are made for every second degree of latitude in Sweden (56°-68°) and also for many other latitudes. Efforts have been made to make an adjustable international sundial but none of the sundials have proved to be so easy in use as this type. This sundial is widely used in town planning in Sweden. Studies have also been made of the penetration of sunlight through windows into a room.

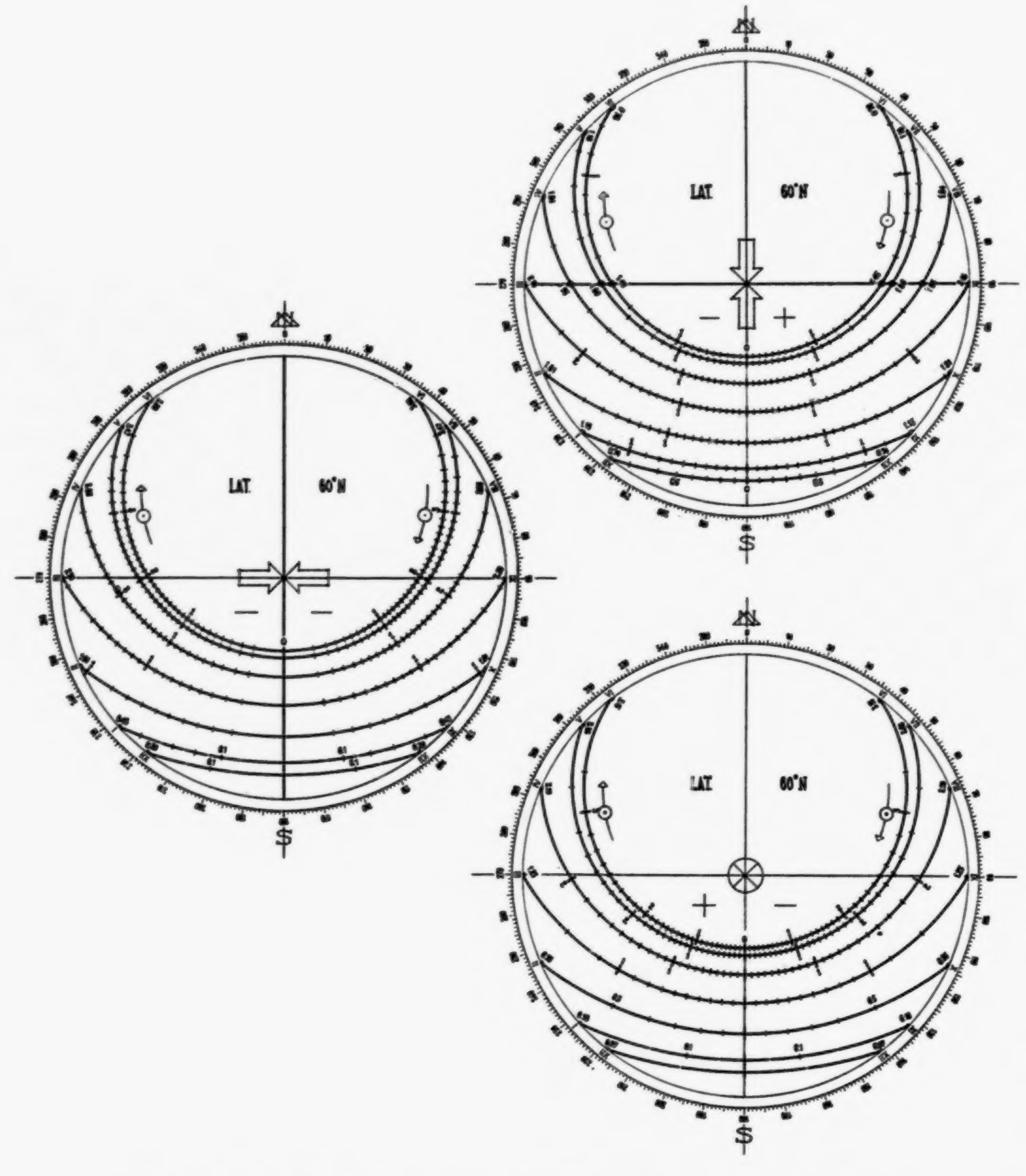

Figure 6 -- Radiation cards for 60° N. Latitude (Stockholm) Valid for clear sky. Unit 370 Btu/ft^2/d. Top: For the x-component (north-south). Left: For the y-component (east-west). Bottom: For the z-component (zenith-nadir).

Tables and Graphs

The calculation methods described here above have been used for some radiation studies. One has been made for southern Sweden (31) and another for a solar heated house at Capri, Italy (40, 43). The result of these studies was comprehensive tables of the radiation

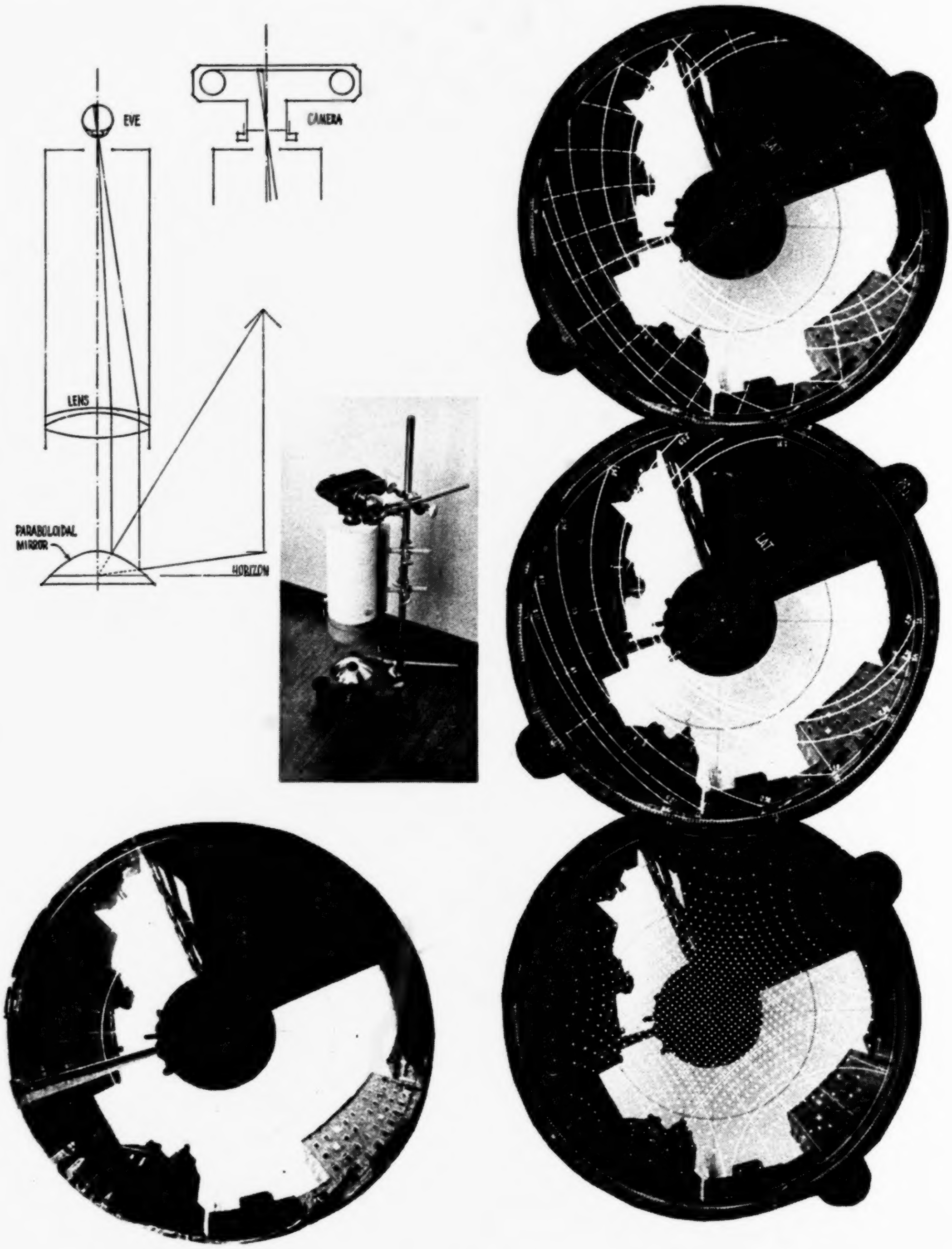
EYE
CAMERA
LENS
PARABOLOIDAL MIRROR
HORIZON
LAT
LAT

Figure 7 -- Top left: The globoscope, a camera arrangement for taking screen pictures of stereographic projection. Bottom left: Screen picture. Top right: The screen picture combined with a solar chart. Middle right: The screen picture combined with a radiation card. Bottom right: The screen picture combined with a component card.

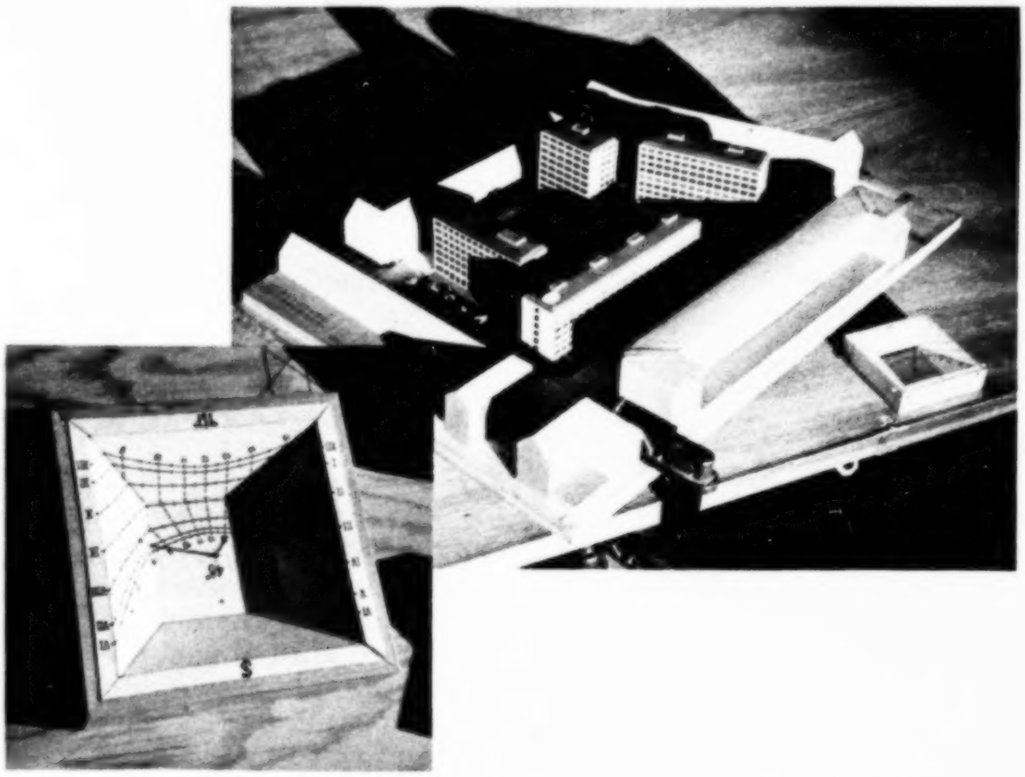

Figure 8 -- Shadow studies with the little sundial and a model. The sundial is placed in proper position on the model. The shadow of the pin indicates the time of day and the time of year for the actual shadow. Shadows for different solar positions can be studied by tilting and turning the model.

on vertical surfaces at 58° N and 40° N Latitude. Tables and graphs are in preparation for four latitudes in Sweden: 56° N, 60° N, 64° N, and 68° N.

The studies for southern Sweden gave tables for the radiation duration and intensities on façades with different orientation and obstruction. Daily totals of radiation were calculated, and graphs of the radiation on façades and ground were plotted. The radiation on a spherical cap with no obstruction was also calculated.

The solar heated house at Capri, Italy, has vertical collectors facing southwest. They are made of panel radiators painted black and covered with glass. Circulating water is heated in the radiators, and the heat is stored in a big water tank. It is then distributed to all parts of the house in a hot water heating system. The calculation of available radiation was made with equations and a solar chart for 40° N. Latitude. The shading effect of a high mountain was considered. Complete tables for all orientations of vertical surfaces and also for surfaces tilting to the south resulted from this calculation.

These tables of radiation at different latitudes will give heating and ventilation engineers information on radiation penetration through windows. As the transmission through glass varies with angle of incidence, it has been considered already at the first stage of the calculation.

GLASS AND SHADING DEVICES

The properties of window glass with respect to the radiation and illumination from sun and sky are of great importance in the design of windows. There are special glasses for different situations, but the common window glass also shows significant differences. Many of the troubles with large windows come from poorly functioning glass.

An investigation of common window glass has therefore been made in Sweden (38, 39). First the spectral distribution of the radiation from sun and sky was determined. Then about 50 different European window glasses (and also some American) were analyzed on their spectral transmission curves. Some of them had a very small absorption while others had an absorption almost the same as for heat-absorbing glasses. This, however, is almost invisible, as the transmission of light is about the same for all glasses. The transmission of the glasses was also measured in an actinometer with a special slide arrangement.

The transmission, reflection, and absorption of radiation by window glass varies also with the number of panes and the angle of incidence. This question is rather complex when there are three or more panes. The problem is further complicated by the reradiation of the absorbed energy. A significant investigation of this field has begun in Sweden (38).

The investigation began with the drawing up of formulas for the primary transmission, reflection, and absorption of the radiation as a function of the properties of the single panes, the angle of incidence, and the number of panes. Efforts were also made to introduce a shading device, but the properties of shading devices are very difficult to obtain. Then the secondary transmission and reflection were studied and also the temperature of the glass panes. Figure 9 (left) gives the total transmission of the radiation through a three-glass window. Figure 9 (right) also gives the temperature distribution in the three-pane window with a heat-absorbing glass outside and common window glass between and inside. The temperature rise of the inside pane is considerable because of the secondary transmission of heat from the other panes.

It is quite clear that the troubles with solar heat gain cannot be solved with heat-absorbing glass (35, 39, 41). This glass only cuts down the daylight and introduces the solar heat by secondary transmission. A combination of heat-absorbing glass and an inside venetian blind gives a worse result than common window glass plus a venetian blind, because the reflection from the blind is absorbed

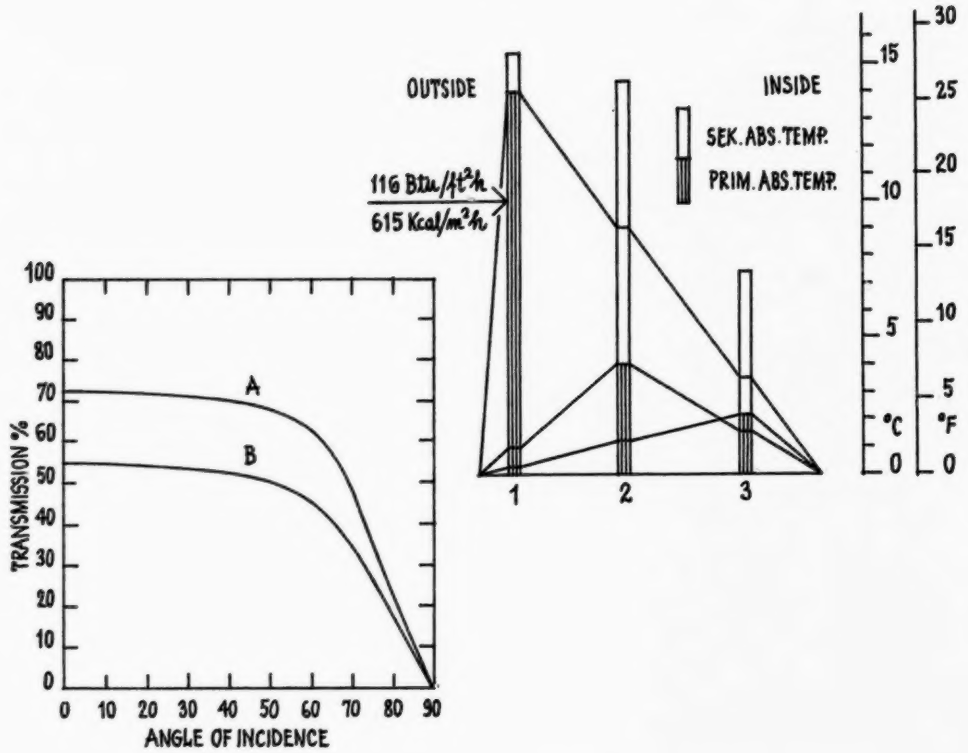

Figure 9 -- Heat transmission and glass temperatures of three-pane windows. Left: Curve A shows heat transmission through three common window glasses; curve B shows heat transmission through a heat-absorbing outer glass and two common window glasses. Right: The temperature of the glass panes in a three-pane window with a heat-absorbing glass outside (same as curve B).

by the heat-absorbing glass and the protecting effect of the blind is diminished.

These problems are somewhat different in Sweden and in the United States, where complete air conditioning must be installed because of the hot outside air in summer. Thus the question of protection against solar heat is only a question of saving the operating expenses. In Sweden the mean temperature of the outside air in July is +17° C (63° F) and thus there is no need for air conditioning. To take care of the solar heat gain through large windows, however, complete air conditioning must be installed if a protecting device is not sufficient. A good protecting device could save both installation and operating expenses of the air conditioning. Heat-absorbing glass and venetian blinds are not sufficient. Therefore investigations are being undertaken along new lines to cut down the heat gain. The protection will be be placed entirely on the blind, giving the whole window as small absorption as possible. The protection shall be by reflection and not by absorption.

In 1952-54 an investigation was made of shading devices against solar heat gain and also against heat loss through windows (32, 42). Nine wooden boxes were used, in which one side was a window of common construction. The windows were provided with shading devices such as venetian blinds, folding paper blinds (translucent or covered with aluminum foil), etc., in most cases between two glass panes.

It was found that the venetian blind was poor protection against the heat from the sun, but good protection against the sunlight. The transmission was between 60% and 85% with somewhat open slats. The folding paper blind was much better, only 35% of the heat penetrating the box. A canvas awning had a transmission of 25%. Best were the aluminum coated paper blinds with a minimum transmission of heat of 15% but they were not translucent.

The boxes were electrically heated inside in the winter, when the radiation from the sun and sky was very weak. The heat insulating properties of the devices as compared with the window without any protection could then be measured. For the unprotected window, the U-value was 0.46 Btu/ft^2/hr/° F. If the window had a venetian blind between the panes (slats closed), the U-value was between 0.31 and 0.36 Btu/ft^2/hr/° F. A folding paper blind in the same position gave the window a U-value of 0.34 Btu/ft^2/hr/° F, and with an aluminum coated blind (both sides) the value was 0.24 Btu/ft^2/hr/° F. It can be seen that shading devices also have good insulating properties, which is an economic factor.

HEAT BALANCE OF WINDOWS

The heat balance of a window is mainly determined by heat gain from sun and sky radiation, and heat loss due to temperature differences between indoor and outdoor air. In hot climates both the radiation and the temperature differences give a heat gain, at least during some part of the year.

The heat balance of windows for the climate of Stockholm has been calculated for different orientations and for an unobstructed sky (33). The window had no protection against the solar heat gain but it was provided with an aluminum coated blind which was pulled down during the hours of darkness and sleep. See Table 1.

From the table it can be seen that for windows with an orientation from southeast to southwest the heat balance is positive during eight months and negative four winter months. The balance during the heating season is positive, which means that the window is self-supporting with respect to heat and also leaves some heat for the demand of the rest of the house. By experiments it has also been found that heat gain through windows plays an important role in the heating of houses (5).

TABLE 1 -- HEAT BALANCE[1] OF A DOUBLE-PANE WINDOW, WITH AN ALUMINUM COATED BLIND PULLED DOWN DURING NIGHT. 60° N. LATITUDE (STOCKHOLM)

Month	Orientation								
	N	NE	E	SE	S	SW	W	NW	NESW[2]
	Heat balance in Btu/ft^2 per 24-hour period Mean value for the month								
I	-246	-246	-232	-179	-146	-179	-232	-246	-214
II	-237	-235	-197	-117	-67	-117	-197	-235	-174
III	-186	-169	-73	+44	+106	+45	-71	-167	-56
IV	-88	-52	+66	+165	+193	+187	+108	-18	+70
V	+40	+76	+215	+292	+286	+332	+321	+178	+215
VI	+141	+164	+288	+344	+346	+385	+417	+297	+298
VII	+179	+210	+340	+400	+392	+445	+456	+325	+342
VIII	+104	+142	+264	+352	+368	+382	+324	+194	+265
IX	+2	+28	+138	+255	+307	+260	+148	+36	+149
X	-103	-100	-47	+42	+98	+42	-47	-100	-25
XI	-186	-186	-168	-115	-82	-115	-168	-186	-151
XII	-221	-221	-214	-179	-158	-179	-186	-221	-202
Average[3] for year	-23.9	-17.5	+12.0	+40.1	+50.4	+45.8	+26.2	-3.8	+16.2
Heating season	-37.2	-34.2	-18.0	+2.3	+12.0	+4.0	-14.1	-30.5	-14.4

[1] Positive balance (+) means that heat gain is greater than heat loss; negative balance (-) means that heat loss is greater than heat gain. Positive balance is enclosed in frame.

[2] Mean value for all orientations.

[3] Btu/ft^2 x 10^3

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Conference Summary

by Wayne F. Koppes, Architectural Consultant

I HAVE TWO DISTINCT REACTIONS as this conference draws to a close. The first is that it has been a very interesting and stimulating two days. Many different aspects of the subject have been discussed by capable men representing many different fields of interest. The members of this planning committee, and in particular its chairman, Orville Pierson, are to be congratulated for the fine program.

My second reaction is that this conference has provided a fine example of the type of program that represents BRI at its best. It has been essentially exploratory in character - an attempt to define various problems, and a review of some of the means at hand to solve them. It has been essentially free of commercialism; in fact, it has been about as close to real building research as we can hope to get in such meetings. Another very commendable feature of this conference has been the participation of our friends from abroad.

REVIEW OF THE PAPERS

Dr. Logan very competently set the stage for our thinking with his keynote address, outlining in an interesting manner seven effects of solar radiation on building design. One observation of his that particularly deserves to be remembered was his statement that "Building is only static clothing - designed to serve a group rather than an individual."

Then Professors Liu and Jordan provided us with quantitative data on the thermal effects of solar radiation, explaining how and where such data are obtained. Dr. Hardy followed with an appropriate sequel -- a scholarly dissertation on the effects of this thermal radiation upon the human skin.

In the next session, the discussion was concerned less with basic theory and data and more with the esthetic and economic aspects of the subject. I'm sure that my architectural colleagues found Mr. Klings's analysis of the esthetics of sunlight and shadow very

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interesting, and found his illustrations inspiring. I wish we might have heard more about the "sun break" wall. It was quite a revelation to learn that one way of reducing the solar heat load to the equivalent of a 40% glass wall is to increase the proportion of glass to 200%.

Professors Queer and McLaughlin then introducd the matter of relative economy, demonstrating that there are many factors to be considered in comparing true overall costs of walls. As I interpreted their studies, with only a brief glimpse at the summary table, two important findings resulted. First, the ultimate costs of masonry, metal, and all glass appeared to be approximately the same; and second, in spite of its high initial cost, double insulating glass was found to be economical in air-conditioned buildings.

Then Mr. Jaros, in his inimitable thorough fashion, summarized for us the highlights of his paper. I have reviewed this paper in detail, and I assure you that it contains a wealth of very useful cost information of great interest to architects. Perhaps his most significant conclusions concerned the effectiveness of heat-absorbing glass, the value of the venetian blind, and the fact that exterior shading devices are usually best for controlling heat gain - if you can afford them.

In the following session, very distinct differences of opinion began to appear. Professor Griffith emphasized that natural illumination produces much less heat gain per foot-candle than electric illumination and therefore provides lower cooling costs. Professor Evans capably and rather romantically extolled the value of skylights. He convincingly argued that the proper source for illumination is through the ceiling, but I think he will agree that this applies chiefly to one-story buildings. Mr. Fisher disputed some of these theories, stating that the only sensible approach to lighting design is to provide all the necessary illumination electrically, supplementing it with daylight when it is available. He even advocates that electric lighting should be intensified, rather than diminished, on the window side of the room. I found this session, on the whole, a little confusing but stimulating.

In the last session, two excellent papers reviewing the work abroad were presented. Mr. Markus gave a comprehensive and scholarly review of the essential considerations influencing proper window design. His principal concern was with visual environment, but he also made some important observations about the noise and the thermal environments. The daylight factor interested me, particularly the fact that illumination in buildings is controlled by legislation in some European countries by reference to this daylight factor. This seems a much more logical basis for control than any I have observed in our own building codes. I made particular note, too, of his statement that "the higher the brightness of the outdoor sky, the higher the levels of the permanent supplementary artificial lighting also have to be." This seems to support Mr. Fisher's position.

Dr. Pleijel's paper provided additional information on the studies of natural illumination which have been going on in Sweden for as long as 30 years. As an architect, I was particularly interested in the typical Swedish window designs, with the shading devices being customarily placed between the glass panes. We are just beginning to see that principle exploited in this country. I was also impressed by the fact that in most cases these designs follow the recommendations of their National Commission on Standards. Dr. Pleijel's introductory sketch of Sweden's climate helped us to appreciate that their concerns with the thermal aspects of solar radiation are somewhat different from ours. I noted, too, that his evaluation of venetian blinds and heat absorbing glass did not seem to agree with that of Mr. Jaros.

NEEDS INDICATED

This subject of Solar Effects on Building Design proves to be a very big one. We have so far dealt with only two of the seven effects that Dr. Logan outlined in his keynote address. Of course these two -- light and heat -- are undoubtedly the most important, but some attention is due the other five. Even under these two headings there are topics which have received little attention - topics such as the design of exterior shading devices, deteriorating effect of solar rays on materials, the insulation of opaque areas, and the beneficial effects of solar radiation. We dealt mainly with undesirable solar effects. Most of our concern has been with air-conditioned commercial buildings, and the unique problems of residential buildings were not given much specific attention.

To summarize, several specific needs have been prominently indicated by this conference:

1. The need for better communication regarding this subject - the need for more generally available information, presented in terms readily understood by the average architect, whose responsibility it is to translate these principles into building design. Instruction concerning insulation against heat gain has thus far received little attention in the architect's formal education, and there is little learned, either, about the science of daylighting.
2. The need for much more objective and unprejudiced research in this field. As long as industry provides the principal support for building research, as it does in this country, thorough and objective as this research is, there are likely to be conflicting results and claims.
3. The need for more BRI conferences on this subject. The committee should be requested to organize more programs dealing in greater depth with only certain segments of the general topic of solar effects.

Open Forum Discussion

Moderator: Henry Wright, Columbia University

Panel Members: Messrs. Markus and Vild[1]

Mr. Wright: I would like to hear the European view of desirable minimum-maximum illumination intensity expounded a bit, Mr. Markus.

Mr. Markus: The general trend has been the same as in the United States, in that we are about doubling our illumination levels every five or ten years. In the U.S.A. and in England and France, we're reaching nearly the top (flat part) of the illumination vs. visual performance curve. On the steep part of the curve (the lower illumination levels), relatively small increments of illumination give you relatively big results in terms of performance. Then the curve bends over fairly sharply near the top and you must double, sometimes even triple, your illumination level for a 1% to 2% increase in performance. This is based on work done by Weston in England which is similar, although older, than work done by Blackwell in this country. The question is: Just how far do you go on that curve to get the extra 1%, 2%, or 3% performance and how much are you willing to pay for it in terms of illumination?

In Europe we have placed much less reliance on illumination levels than on quality of illumination. Admittedly, a lot of British codes have been, at least in the past, entirely in quantity terms, but architects have not simply taken these and followed them literally.

The rising illumination levels that are now recommended are almost impossible to meet from daylight alone for 90% of the working hours in many buildings, unless you keep the rooms very shallow and very high, which is uneconomical. It is with this idea in mind that the work referred to in my paper has been done on permanent supplementary artificial lighting. The whole basis of that work is to supplement the daylight permanently but to treat daylight nevertheless as visually your primary source of light, because we consider this psychologically important. The work has shown that subjectively the brighter it gets outside, as long as there are any lights on at all inside, the higher your illumination level has got to be inside. At first this sounds paradoxical, but if it gets bright outside and your inside level is very low, you immediately judge it to be gloomy and dark when, in fact, if you measured it photometrically it would be more than adequate from the code point of view. Many systems which control light by photo cells have failed because they switch the lights off when it gets brighter outside, which is exactly the reverse of what you want to do.

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[1] Donald J. Vild, Technical Service Engineer, Libbey-Owens-Ford Glass Company, made the oral presentation of Gunnar V. Pleijel's paper and represented him in the Open Forum Discussion.

Mr. Wright: I had the experience some years ago of putting quite dark gray glass in a window in an office in Rockefeller Center. The office was illuminated with a plastic shade semi-indirect lighting fixture that today would be regarded as very poor quality. The gray glass made the electric lighting suddenly appear to be very up to date and effective; having, in effect, made the outside less bright, the gray glass made the inside quite a lot brighter. We can be content with considerably less electric illumination if we have a means for reducing outdoor brightness such as that provided by low transmission glass.

Large windows in the past have been regarded as a free source of illumination. If we want a great deal of illumination with a minimum of heat, we can get it best from outdoors because our electric lighting equipment doesn't compare in efficiency of light output with the sun. It is quite possible that skylights can be shown to completely pay for themselves in reduced installation cost of air conditioning equipment. In fact, a very reasonable combination would be skylights and low transmission windows.

Mr. Wright: The venting of the double windows in Swedish practice is done in order to prevent condensation between the windows. Is there sufficient venting to offer a means of excluding solar heat, if we were to use a heat absorbing outer sash?

Mr. Vild: The vents in the Swedish design are only one millimeter wide. Their purpose is to equalize vapor pressure differences, and since the air space will generally be warmer than the outside air, no condensation should take place. I don't think they are large enough to carry off heat due to solar energy. For this purpose, larger vents would be needed.

Mr. Wright: Is there any experience abroad with heat-reflecting glass as opposed to heat-absorbing glass?

Mr. Markus: It is now available in Europe, made by the Belgian glass manufacturers, generally in the form of a heat-reflecting coating on the inner surface of the outer pane of a double glazing unit. Since it is very vulnerable to corrosion and scratching, you can't use it on an exposed glass surface. Actually, the light travels twice through the outer pane of glass. Of course, there is a reduced light transmission.

It amazed me very much that when heat-absorbing glasses, shades, and similar devices for exclusion of solar heat were listed in order of efficiency, nobody used any yardsticks. One cannot assess the efficiency without reference to light. It is the heat-to-light ratio that should be the yardstick, rather than the heat exclusion alone.

Mr. Wright: Is that consistent with the fact that we are deliberately making the windows of low transmission?

Mr. Markus: You do not need the low transmission at the times when you are most worried about solar heat absorption. It is the overcast, cloudy sky that is a real worry from the glare point-of-view. On clear days, you have no worry about glare unless you're actually looking at the sun, because a blue sky is one of the most comfortable things you can look at. An overcast sky is ten times as bright.

Mr. Wright: Blue skies sometimes have sunlit clouds floating around in them.

Mr. Markus: Yes, but generally one does not associate the acute glare problem with the same days as acute solar heat problems. The glare problem arises in winter, spring, and autumn. In the summer when you have heat and high temperatures, you would not have the glare problem unless you are thinking of glare from the sun which probably cannot be dealt with by means of glare-reducing glass, but needs to be dealt with by shading.

R. P. G. Pennington, Board of Education, Toronto, Canada: Can you defend double glazing for solar control as being heat-absorbing or solar reflecting?

Mr. Vild: In your area, where you have cold-climates, heat-absorbing type insulating glass becomes a particularly effective device. In the colder weather, heat lost through this type of glass is on the order of 50% or 60% of what it would be for single heat-absorbing glass or single regular plate glass. I think this is an appreciable savings and will also improve comfort conditions.

Mr. Wright: I happened to see a picture in the New York Times of a college building where a wall about three stories high had been provided with a heat-absorbing glass screen. It was set out from the building about 18 inches in a grid of aluminum, I believe, and behind it the air could freely circulate. Unquestionably, the circulation of outdoor air behind such a heat-absorbing device offers enormously more promise. If you are going to try to use a transparent heat-absorbing plane, the outdoor air must be able to circulate behind it and carry away the heat.

This applies to a great deal of construction, by the way. We need holes that will let the hot air out. At Columbia University, we are studying the effect of this type of ventilation in a little sample of roof construction. If the air in the cavity in the roof heats up to 130° or so, and if you can provide an outlet through which it can escape, it will carry away a lot of unwanted heat with it.

It would be ridiculous to buy a sealed double glazing as a means of keeping out solar heat. You can buy sealed solar glazing as a convenient method of heat conservation in the wintertime with freedom from trouble and so on, and it will eventually pay for itself, as any form of insulation must. It would take a terribly long time for it to pay for itself in air conditioning savings, and except as a stopgap method of improving comfort, I don't think it's at all a promising idea. The sealed double glazing developed in this country, with or without a heat-absorbing outer layer, is mainly used to reduce the loss of expensive heat in the winter. It cannot be justified economically for the sole purpose of reducing heat gain in the summer.

Mr. Vild: Very definitely, you can economically justify heat-absorbing type glass on an air conditioning basis. Taking into account that with the common shading devices, the heat gain is reduced 30 to 40% over single glass, and taking into account the initial and operating cost for the building, I believe that in every area of the country there can be shown an economic justification, on an annual owning and operating cost basis, for heat-absorbing type insulating glass.

Mr. Wright: A good deal of your justification would be winter-heat saving, wouldn't it?

Mr. Vild: Yes, but you have to take the whole picture into consideration. If you have to pay for the buildings year by year, as well as paying the initial costs, you are always ahead with the heat-absorbing insulating glass.

Mr. Markus: While you have expressed some doubt about the question of sealed double glazing units with heat-absorbing glass, nobody would deny that it's very much more efficient to have a double glazing system which is fully ventilated to the outside, provided it is technically feasible. Your inner glass then acts as a shield against long wave radiation and the air current takes away the built-up heat from both glasses. This is what was done in the UNESCO Building. You have a double glazing system there where the heat-absorbing glass is projected about 2 or 3 feet outside of the window. But, if you do that, you have two problems: first, you must seal it again for the winter, otherwise, you lose the value of the air space; second, you have cleaning problems, because as you bring your ventilation through, you also dirty the inner faces. This means that you've got to be able to get in and clean the two inside glass surfaces.

Mr. Wright: The European practice of building double windows as two separate complete sashes would be a virtue in this case. Such a window has recently been introduced in the United States. It is necessarily more expensive than the one sash.

S. H. Walter, E. I. duPont de Nemours & Co., Inc.: How is the paper window shade described by Dr. Pleijel operated?

Mr. Vild: One method is similar to the way our venetian blinds work, but with the cords coming through the framing. Another method is by means of a gear which you spin with your thumb. It is necessary to have an opening for the cords or for the gear.

Mr. Markus: The most common kind of paper blind is a concertina. It is a folded-up paper blind with inch folds and the cords actually go through holes in the sides of the concertina. You just pull the cord and the whole thing collapses and is pulled up to the top of the window; and it just drops by gravity when you release the cord. Frequently, one surface of the paper is metallized. Dr. Pleijel has done work on metallized paper blinds. As he points out, a window in Sweden has a curtain or blind 50% of its time at night. The value of the thermal insulation of the air space is about doubled by having a metallic surface on one side of the blind at night. Thus, the heat losses are considerably reduced.

S. E. Persson, AMELCO: Mr. Fisher says in view of the fact that air conditioning equipment costs more than six times as much as heating equipment, it would require more than six times as much investment to air condition out the lighting heat gain in the summer to offset the gain in winter. How can you not regard air conditioning loads from electric lighting as you suggested?

Mr. Vild: In every case it costs you a lot more to get rid of a Btu than it costs to make it. Where you reduce your heating requirements, but increase your air conditioning requirements by the same amount, it is going to cost you more to operate the system. So, I don't think on an annual basis there's any advantage;

in fact, I'm pretty certain there's considerable thermal disadvantage to using electrical illumination for heating.

S. E. Persson, AMELCO: Lights are on only eight hours out of 24 and usually during the warmest part of the day. How can you justify this as heat gain?

Mr. Markus: One answer would be that the heat output from lighting is as least partly radiant and is absorbed by the floor and released later on. But, I think that is also the criticism. It is all very well for Mr. Fisher to say that you can provide all the heat you need in winter from your lights, but you are going to have some very dissatisfied people in your building.

Mr. Wright: I suspect that Mr. Fisher had in mind certain arrangements, such as the one where air is drawn out through the lighting fixtures, acquiring a fairly high temperature in the course of being drawn out, and then is taken to other parts of the building where the heat is badly needed. There is an office building in Oklahoma City which is heated in the daytime by a combination of electronic equipment, lighting, and sun. They store in a water tank in the daytime enough heat to keep the building warm overnight. When they have to, they buy off peak electric power to supplement the heat in the storage tank.

There are 101 tricks coming along in this field. The one of extracting heat from the middle of a large building such as a suburban department store and using it in the perimeter space is fairly common.

Mr. Markus: This is all right if your lighting system gives off most of its heat in the form of sensible heat that you can remove. Most lighting systems give out a good deal of direct radiant energy, and there is no way of removing that by any amount of ducting. If this is a large element of your heat input, you are going to get discomfort. If you convert radiant heat by heat absorbing filters and covers into sensible heat and immediately remove it, it can work but you reduce lighting efficiency. Then you have to increase your light input to get the same amount of light out. It is a vicious circle.

Mr. Wright: Mr. Fisher would probably assert that they have recovered about 60% of the heat from open bottom fixtures with fluorescent lamps in them.

Question from audience: Will a louvered aluminum insect screen stand up in the form of a roller shade?

W. Schreckengast, Kaiser Aluminum: The manufacturers don't recommend rolling and rerolling it.

Mr. Victor Olgyay, Princeton University: We have done some recent work on sunshading and the effectiveness of different shading devices. Outside shading devices are from 20% to 40% more effective than inside shading devices, because they intercept the sun before it reaches the glass. Plastic sheeting materials can be applied on the glass, but they don't work very efficiently; the metallic coatings on the glass have a 20% higher efficiency. Outside shading devices which are movable are the most effective. Our studies have shown, based on medial values, that shading devices may be rated in this order: outside movable shading devices (most effective), metal blinds, shade screens, outside fixed shading devices, outside awnings, trees, coatings on glass surfaces, insulating curtain, tinted glass, roller shades, and venetian blinds (least effective).

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